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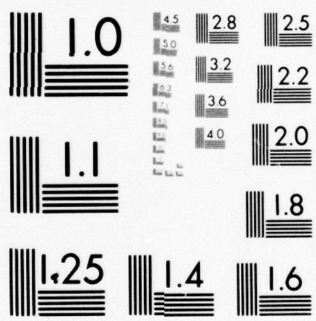

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Report No. CG-D-32-79

AIRBORNE EVALUATION OF THE PRODUCTION AN/ARN-133 LORAN-C NAVIGATOR

July 1979

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Final Report

Prepared for

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16. Abstract

This report presents the results of a comprehensive flight test evaluation of a production airborne Loran-C navigator. The tests were performed on an FAA approved helicopter route in the Northeast Corridor, at NAFEC in Atlantic City, New Jersey and in the Gulf of Mexico. The test aircraft used were United States Coast Guard HH52 and HH3 helicopters. The test period was from June 1978 to January 1979. The test plan and test objectives were developed jointly by the United States Coast Guard and the Federal Aviation Administration and Systems Control, Inc. (Vt), Champlain Technology Industries Division. The flight test profiles and procedures were developed for the following reasons: 1) to assess the acceptability of Loran-C navigation in the operational ATC environment of the Northeast Corridor; 2) to determine the system use accuracy for Loran-C for enroute, terminal and non-precision approach flight; 3) to evaluate the Loran-C navigator performance in several offshore missions.

The primary conclusions of this flight test evaluation were: the navigator was acceptable in the operational environment of the Northeast Corridor for both enroute and point-in-space approaches; the navigator satisfied AC 90-45A crosstrack accuracy requirements for enroute, terminal area and non-precision approaches; the production navigator satisfied alongtrack AC 90-45A accuracy requirements for enroute and terminal area, but not for non-precision approaches; the navigator performed acceptably during all phases of offshore testing.

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PREFACE

The Office of Research and Development of the United States Coast Guard in conjunction with the Systems Research and Development Service of the Federal Aviation Administration has sponsored the airborne evaluation of the production AN/ARN-133 Loran-C navigator. An operational and accuracy evaluation was performed to assess functional capability and usability of the AN/ARN-133 within the National Airspace System. This work was performed under the Air Navigation Requirements Study Contract to Systems Control, Inc. (Vt), Contract Number DOT-FA75WA-3662 Task X. Primary responsibility for this contract was assigned to the Champlain Technology Industries Division.

The USCG technical monitor for this work was Mr. David Firestone and the FAA technical monitor was Mr. George Quinn. The program manager and principal author of this document was Mr. R.J. Adams of CTI. The major efforts of data acquisition, flight test coordination and day-to-day program activities were contributed by Mr. J.B. McKinley of CTI.

The scope of this flight test evaluation was quite broad and included a coordinated set of USCG and FAA test objectives. Test planning, data collection and data analysis was performed in the Northeast Corridor, the Gulf of Mexico, offshore over the Atlantic Ocean and at Atlantic City, New Jersey. The degree of complexity and scope of this program required a high level of support from the entire project team. The following list summarizes the team members, lists individual areas of responsibility and is meant to recognize the important role and functions performed by each member.

E.H. Bolz (CTI)	-	ARTS III data collection coordination and primary responsibility for data reduction and statistical processing software development.
L.D. King (CTI)	-	Engineering and data reduction support.
B.W. Richards (CTI)	-	Engineering graphics support and data presentation.

A critical role in this program was fulfilled by the subject pilots used during the flight tests. The pilots were selected at random from the ranks of the United States Coast Guard Air Station personnel. Operational helicopter crews were used from Cape Cod Air Station located at Otis Air Force Base, Massachusetts; Cape May Air Station in New Jersey and the Aviation Training Center located at Bates Field in Mobile, Alabama. A special effort was performed by the primary project pilots. Specifically, LCDR J. Perry at Otis; CDR R. Long, LCDR D. Howard and LCDR L. Manfra at Cape May; LCDR J. Okon and Lt. T. White at Bates Field provided enthusiastic support from an airborne operations viewpoint throughout the

test period. The primary subject pilots were supported by crew members (acting as pilot or copilot) on an as available basis from the following list:

CDR Tanguay	Cape May
LCDR Bosma	Cape May
LCDR Garrity	Cape May
LCDR Peoples	Cape May
LT Evans	Bates Field
LT Salamone	Cape May
LT Touzin	Otis

Finally, an invaluable and meticulous effort was performed by three important individuals. Ms. K.M. Cinefra, Ms. J.A. Williams and Ms. S.M. Fournier performed the arduous task of typing and retyping necessary to produce this document.

A great and sincere thanks is extended to each of these team members without which this report would not have been possible.

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ABBREVIATIONS AND ACRONYMS

AC 90-45A	-	Federal Aviation Administration Advisory Circular 90-45A
AFB	-	Air Force Base
AGL	-	Above Ground Level
AN/ARN-133	-	Production version of the Teledyne TDL-424 prototype airborne Loran-C navigator
AP	-	Approach Point
ARTS IA	-	Automated Radar Terminal System version IA
ARTS III	-	Automated Radar Terminal System version III
ASC II	-	Teledyne data link subsystem
ASE	-	Airborne System Error
ATC	-	Air Traffic Control
ATD	-	Alongtrack Distance
ATE	-	Alongtrack Error
AUTO	-	Automatic
BAL	-	Baltimore/Washington International Airport and TRACON
BCD	-	Binary Coded Decimal
BDL	-	Bradley International Airport and TRACON
BELL 202C	-	Collins Model 1200 Modem
BLTP	-	Base Leg Turn Point
BOS	-	Logan International Airport and TRACON
BRG	-	Bearing
CDC	-	Computer Data Corporation
CDR	-	Commander
CLR	-	Clear
CSP	-	Commence Search Point
CTD	-	Crosstrack Deviation
DCA	-	Washington National Airport and TRACON
DIST	-	Distance
DME	-	Distance Measuring Equipment
d_{rms}	-	Distance Root-Mean-Square
DSR TK	-	Desired Track
DTW	-	Distance To Waypoint
EAIR	-	Extended Area Instrumentation Radar
E ERROR	-	Easting Error
EWR	-	Newark Airport and TRACON
FAA	-	Federal Aviation Administration
FF	-	Flight Following
FR	-	From
FTE	-	Flight Technical Error
HELO	-	Helicopter
HH3	-	USCG twin engine amphibious helicopter
HH52	-	USCG single engine amphibious helicopter
HRS	-	Hours

ABBREVIATIONS AND ACRONYMS
(continued)

ID	-	Identification
IDENT	-	Transponder identification of an aircraft to ATC
IFR	-	Instrument Flight Rules
ILS	-	Instrumented Landing System
JFK	-	John F. Kennedy International Airport and TRACON
LAT	-	Latitude
LCDR	-	Lieutenant Commander
LGA	-	LaGuardia Airport and TRACON
LON	-	Longitude
LOP	-	Lines Of Position
Loran AT	-	Loran-C Alongtrack Error
Loran CT	-	Loran-C Crosstrack Error
LT	-	Lieutenant
M	-	Mean Error
MAG VAR	-	Magnetic Variation
MAP	-	Missed Approach Point
MEA	-	Minimum Enroute Altitude
MSL	-	Mean Sea Level
NAFEC	-	National Aviation Facilities Experimental Center
NAS	-	National Airspace System
NAS	-	Naval Air Station, Quonset Point TRACON
NAV	-	Navigation
NEC	-	Northeast Corridor
NFDI	-	Navigation Flight Director Indicator
NM	-	Nautical Miles
NPA	-	Non-Precision Approach
PHL	-	Philadelphia International Airport and TRACON
POS UPD	-	Position Update Mode
PISA	-	Point-In-Space Approach
RHO	-	Distance or Range
RNAV	-	Area Navigation
RSS	-	Root-Sum-Square
RWY	-	Runway
SAR	-	Search And Rescue
SID	-	Standard Instrument Departure
STAR	-	Standard Terminal Area Route
TCA	-	Terminal Control Area
TD	-	Time Difference
TDA	-	Time Difference word "A"
TDB	-	Time Difference word "B"
TDL-424	-	Teledyne prototype airborne Loran-C navigator Model 424
TDL-414	-	Teledyne antenna coupler unit for the production AN/ARN-133 airborne Loran-C navigator

ABBREVIATIONS AND ACRONYMS
(continued)

TDL-471D - Teledyne airborne data link Decoder
TEB - Teterboro Airport
THETA - Bearing
TI SILENT 700 (Model 743-KSR) - Texas Instruments Printer Terminal
TK - Track
TKE - Track Angle Error
TN - True North
TOTAL CT - Total System Crosstrack Error
TSCT - Total System Crosstrack Error

USCG - United States Coast Guard

VFR - Visual Flight Rules
VOR - Very High Frequency Omnidirectional Range
VORTAC - VOR/TACAN (VOR/Tactical Air Navigation)
VS - Versus

W/O - Without
WTC - World Trade Center heliport

XTK - Crosstrack Distance

ρ - RHO (Range)

θ - Theta (Bearing)

σ - Sigma (Standard Deviation)

2D - Two-Dimentional Navigation, i.e., lat/lon, TDs

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1.0 EXECUTIVE SUMMARY

An extensive flight test evaluation was performed on the production model of the AN/ARN-133 airborne Loran-C navigator made by the Teledyne Systems Company. The evaluation was conducted from June 1978 through January 1979. Data was collected on the operational characteristics and system accuracy in three basic environments. Loran-C operation in the National Airspace System was evaluated primarily in the high density Northeast Corridor environment between Boston, Massachusetts and Washington, D.C. Loran-C system accuracy testing was performed primarily in the vicinity of the National Aviation Facilities Experimental Center (NAFEC) at Atlantic City, New Jersey. Loran-C overwater signal characteristics, absolute accuracy and repeatability were evaluated during tests in both the Gulf of Mexico and the coastal waters near Atlantic City, New Jersey. This report addresses the objectives, the data collection plans, the flight test procedures, the quantitative and qualitative results and the conclusions which evolved from this investigation.

The airborne Loran-C evaluation contained in this report was initially sponsored solely by the United States Coast Guard (USCG) as a part of the effort to establish Loran-C as the primary navigation system used to support their operational mission. Due to the need for the Coast Guard operations to integrate with conventional VOR/DME navigation in the National Airspace System (NAS), the USCG portion of the program included NAS compatibility demonstration flights. Upon successful completion of the initial demonstration by the USCG, the Federal Aviation Administration (FAA) examined the preliminary results and expressed an interest in supplementing the Coast Guard test program in order to gather additional data pertinent to the FAA interests. This report, therefore, presents the results of the joint USCG and FAA evaluation programs. These results primarily address the production AN/ARN-133 navigator. An additional published report, "An Operational Flight Test Evaluation of a Loran-C Navigator", CG-D-9-77, dated March 1977, deals with the preliminary flight test results obtained on the prototype TDL-424 Teledyne Loran-C navigator.

This document integrates the significant results from the production and prototype Loran-C tests performed to date. In order to organize the data and simplify the comprehension of the many results from these programs, this report categorizes the data into three main categories:

- Northeast Corridor Operational Testing
- NAFEC System Accuracy Testing
- Offshore Testing

1.1 DESCRIPTION OF THE FLIGHT TEST PROGRAMS

The Northeast Corridor (NEC) operational testing entailed flying the production Loran-C navigator under visual flight rules with conventional VOR/DME traffic under air traffic control at altitudes varying from 500 to 4500 feet. Enroute segments were flown with lengths varying from 167 nautical miles to 394 nautical miles. Transition routes to and from the corridor were also evaluted. These transition, or spur,

routes are currently being flown by Sikorsky Aircraft, Mack Trucks, RCA and New York Airways, using VOR/DME RNAV techniques. The purpose of the test flights were to obtain Loran-C operational compatibility and accuracy data in this conventional environment. Final approach testing in the NEC was accomplished for two types of approach procedures. Point-in-space approaches (PISA) were flown in the Boston, New York and Washington, D.C. areas and non-precision approaches (NPA) were flown in Frederick, Maryland and Boston, Massachusetts. These Northeast Corridor flights were performed using both the HH3 and HH52 helicopters.

The NAFEC system accuracy testing consisted of both prototype (TDL-424) and production (AN/ARN-133) Loran-C navigator testing. Enroute data was collected at altitudes varying from 750 feet to 2500 feet between Cape May, New Jersey and NAFEC. Enroute segment lengths varied from 24 nautical miles to 37 nautical miles. Terminal area maneuvering data was also collected using both versions of the Loran-C navigator. Standard Instrument Departures (SIDs) and Standard Terminal Arrival Routes (STARs) were flown to and from runway 04 at NAFEC. The basic design of these SIDs and STARs was derived from routes developed from the New York-Kennedy terminal area as described in Reference 1. Finally, non-precision approach data was collected using both the prototype and production navigators in three modes of waypoint definition; non-updated latitude and longitude, updated latitude and longitude, and time differences. Both the HH3 and HH52 helicopters were flown to obtain enroute, terminal and approach data.

Offshore testing of the Loran-C navigator was performed in the coastal waters off of Atlantic City, New Jersey and in the Gulf of Mexico. Data was obtained on both versions of the navigator during Search and Rescue (SAR) and surveillance modes of operation in the Atlantic Ocean. Only the production navigator (AN/ARN-133) was tested in the Gulf of Mexico as well as the Atlantic Ocean. Data collection on the AN/ARN-133 consisted of deep probes overwater (out to 200 nm) and coastline signal anomaly tests over the Atlantic, as well as Ship/Helo rendezvous procedures development and oil rig tests performed in the Gulf.

1.2 PROGRAM OBJECTIVES

The flight test evaluation of the production model of the AN/ARN-133 airborne Loran-C navigator was designed to satisfy several general, or overall, objectives. These can be summarized for each of the three major data collection categories as follows:

<u>Northeast Corridor Operation Testing</u>

1) To demonstrate operation of the Loran-C navigator in the Northeast Corridor operational ATC environment.

2) To verify the navigation accuracy and functional performance of the production version of the AN/ARN-133.

3) To provide specific data relative to Air Traffic Control operations and pilot workload requirements while transitioning to and from the Northeast Corridor utilizing the Sikorsky, Mack Truck, RCA and New York Airways routes.

4) To provide additional Loran-C non-precision approach data which will supplement previously acquired AN/ARN-133 and TDL-424 approach data obtained at NAFEC.

5) To evaluate Loran-C as an approach aid to point-in-space approaches and to unaided helipads.

6) To acquire preliminary data on VOR/DME signal coverage at low altitudes in the Northeast Corridor.

NAFEC System Accuracy Testing

1) To supplement the previously acquired Loran-C navigator IFR certification data, for AC 90-45A compliance, for operations in both HH3 and HH52 helicopters.

2) To evaluate the production version Loran-C navigator telemetry data link function as a low altitude aircraft surveillance tool.

Offshore Testing

1) To demonstrate operation of the Loran-C navigator during long range (100-200 nm) overwater missions.

2) To investigate the potential Loran-C signal anomaly peculiar to coastline overland/overwater transitioning.

3) To evaluate the Loran-C navigator as an approach aid to the flight decks of ships and offshore oil rigs.

4) To verify that the previously acquired prototype Loran-C Search and Rescue and surveillance accuracies can be attained by the production navigator.

1.3 METHOD OF APPROACH

The basic test program consisted of the three major categories of dedicated flight testing described in Section 1.2. These were defined as Northeast Corridor Operational Testing, NAFEC System Accuracy Testing and Offshore Testing. This section discusses the details for each of these categories including number of flights, flight hours by major category, types of segments flown, total miles flown and the specific aircraft used (HH3 or HH52).

To facilitate data collection, each of the major test categories were subdivided into specific research areas as follows:

1) Northeast Corridor Operational Testing

   A) Enroute
   B) Transition (spur) Routes
   C) Final Approach Testing

2) NAFEC System Accuracy Testing

   A) Review of Prototype Navigator Data Base
   B) Development of the Production Navigator Data Base
   C) Telemetry Tracking with Loran-C

3) Offshore Testing

   A) Deep Probes Overwater
   B) Coastline Signal Anomalies
   C) Ship/Helo Rendezvous
   D) Oil Rig Tests
   E) Search and Rescue Tests

Each of these research areas were then allocated test time using the production navigator on each of the test aircraft. As previously indicated in Section 1.0, these major test categories contained data pertinent to both USCG and FAA objectives regarding Loran-C implementation in the National Airspace System.

Figure 1.1 summarizes the integrated FAA and USCG Loran-C flight test program. As shown in Figure 1.1, the scope of the integrated program was 93.4 hours. From this total flight time, over 6500 nautical miles of enroute data was obtained. The majority of this data (4133 nm) was collected flying the high density "Northeast Helicopter Corridor Routes from Washington, D.C. to New York City and from New York City to Boston". These routes have been approved by the FAA for area navigation at low altitudes (approximately 1500-4500 feet). The Jeppesen Company published a chart of these routes in December 1978. These routes have numerous closely spaced waypoints for a variety of reasons. First, these waypoints are required to accommodate the VOR/DME users who are constrained by line-of-sight coverage limitations. Second, these waypoints are required by VOR/DME users to insure operation within the reduced (±2 nm) route width of these routes. Third, these waypoints are used to support and integrate with ATC procedures. Fourth, these waypoints insure adequate obstacle clearance. The northbound route has 22 waypoints with minimum spacings of less than five nautical miles and a maximum spacing of 47 nautical miles. Average waypoint spacing is only 15 nautical miles northbound. Similarly, the minimum, maximum and average waypoint spacings on the southbound route were five, 44 and 16 nautical miles, respectively. During these tests, the Loran-C navigator was operated in the latitude/longitude input mode according to the pilot's handbook supplied by the manufacturer. Alternate northbound and southbound routes were flown in both the non-updated and the preflight updated modes.

Included in this enroute data base was the Loran-C evaluation of the transition, or spur, routes currently flown to and from the Northeast Corridor by various users. These spur routes, in general, had even closer waypoint spacing and larger turn magnitudes (therefore higher pilot workload) than the published routes. The purpose of using Loran-C on all of these enroute segments was to demonstrate operational compatibility in today's ATC environment and to obtain data (using ARTS III and IA surveillance radar) on Loran-C accuracy. In addition, functional compatibility data

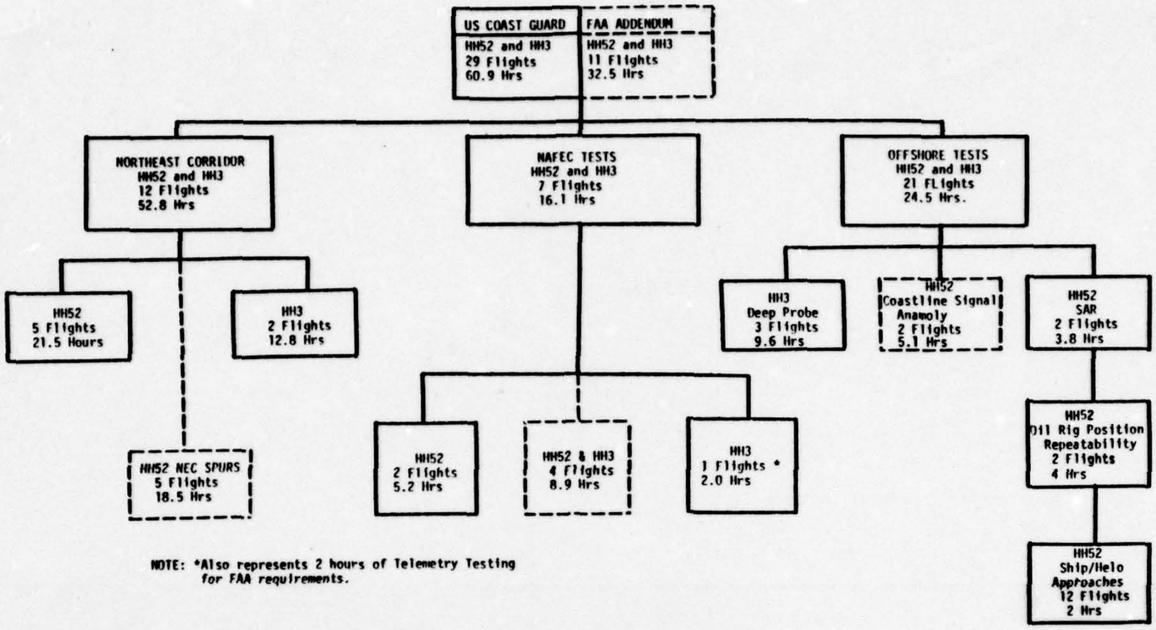

Figure 1.1 Integrated FAA and USCG Flight Test Program Summary

on the production AN/ARN-133 Loran-C navigator was obtained as far as waypoint storage capability (the navigator stores nine waypoints) is concerned. A further discussion of the specific routes flown, pilot navigation procedures, altitudes flown, navigator characteristics, etc., can be found in Section 4.0 and Appendices A, B and C.

As shown in Figure 1.1, the NAFEC System Accuracy Tests were flown solely in the HH3 and HH52 aircraft with the production Loran-C navigator. This data was acquired to supplement the previous enroute, terminal and non-precision approach accuracy data collected with the prototype navigator in the HH52 aircraft (Reference 2). Figure 1.1 shows a total of 7.2 hours of NAFEC System Accuracy testing. As will be discussed in Section 4.0, this translates into 185 nautical miles of enroute data, 348 miles of terminal area maneuvering data and 40 approaches were flown in the HH3 and HH52 using the AN/ARN-133. This data base augments the previous data collected in the HH52 aircraft using the TDL-424 prototype Loran-C navigator. Two hundred and sixty eight nautical miles of data were collected enroute, 362 nautical miles in the terminal area and 18 non-precision approaches were flown in the HH52 using the prototype Loran-C navigator.

The amount of data collected (sample sizes) was chosen to insure adequate statistical data reliability as described in Reference 1. The data was reduced into total system error, flight technical error, alongtrack error and airborne equipment error statistics for each type of airspace (aggregate statistics) and for each route segment flown in each of the airspace regions. The ground reference data for these NAFEC System Accuracy Tests was obtained using the "Extended Area Instrumentation Radar" (EAIR) installed at NAFEC. The precision of the EAIR is quoted as being accurate to within 20 yards in slant range, 11 thousandths of a degree in azimuth and elevation angles, out to a range of 190 nautical miles when

operated in the beacon tracking mode. This mode was used for both prototype and production Loran-C testing. The data base recorded during these experiments, in conjunction with those reported in Reference 2, can be used for demonstration of compliance with the area navigation requirements of FAA Advisory Circular 90-45A, "Approval of Area Navigation Systems in the U.S. National Airspace System".

In addition to the accuracy testing performed at NAFEC, the FAA requested that a demonstration of the Loran-C navigator's telemetry function be performed. This data was of interest for possible applications to low altitude aircraft tracking for helicopter operations in general and for offshore oil rig operations in particular. A single flight was performed, entirely overland, to demonstrate this function. Real time aircraft telemetered position was recorded, as well as the EAIR indicated aircraft position.

The third major category of the integrated FAA and USCG Loran-C flight test program encompassed offshore operations. Figure 1.1 shows that these operations included both HH3 and HH52 test aircraft flying various profiles. In general, the HH3 was used for the longer duration flights due to its range capabilities. These included the deep probes overwater which ranged from 160 nautical miles to 200 nautical miles. The HH52 was used on a coastline signal anomaly test flown at dawn which zig-zagged across the coastline (five miles overwater and five miles overland) for a total along track distance of 145 nautical miles covering 40 miles of coastline. The HH52 was also used for the complementary dusk coastline signal anomaly test which was abbreviated in length due to aircraft range limitations. The dusk coastline flight of the HH52 covered 166 miles along track and 46 miles of coastline distance.

In addition to the coastline signal anomaly test, the HH52 flew two search and rescue patterns and two surveillance tests to substantiate prototype Loran-C navigator test results on these typical USCG operational scenarios. The search and rescue patterns covered a distance of 270 nautical miles. The surveillance tests required 280 nautical miles of enroute flying.

Finally, the HH52 was used for the Ship/Helo rendezvous procedures development performed in the Gulf of Mexico. The Loran-C navigator was utilized to simplify rendezvous procedures with both fixed and moving vessels. Preprogrammed waypoints, the navigator's ability to establish a new RHO/THETA waypoint from a preprogrammed fix, and the present position direct-to capability, were all used to develop a more accurate rendezvous with straightforward procedures requiring less pilot workload and reduced subjective judgement necessary on the part of the flight crew in order to perform the rendezvous.

A more detailed description of each of the three major categories of Loran-C flight testing is presented in Section 4.0. The AN/ARN-133 navigator operating characteristics and capabilities are discussed in Appendix A. The flight profiles for the Northeast Corridor routes, the NAFEC routes, and the Offshore routes are described in Appendix B. The detailed data collection and processing procedures are presented in Appendix C.

1.4 PRIMARY RESULTS

This section presents an overview of the primary results of the flight test evaluation of the production AN/ARN-133 Loran-C navigator. The results are discussed and correlated for the individual test objectives previously presented in Section 1.2. The results are organized according to the three major test areas. Detailed data pertinent to each result may be found in Section 5.0 under the identical test area heading.

Northeast Corridor Test Results --

The first major test area was the evaluation of Loran-C in the high density Northeast Corridor operational environment. The primary areas of concern were the operational compatibility of Loran-C and the capability of the navigator from both functional and accuracy viewpoints. These primary concerns are discussed and resolved in the results summary which follows.

OBJECTIVE

1. To demonstrate operation of the Loran-C navigator in the Northeast Corridor operational ATC environment.

RESULTS

The Loran-C navigator performed satisfactorily in the high density operational environment of the Northeast Corridor. This performance was within the reduced enroute route widths established by the FAA for this special helicopter route. These results were obtained during normal daytime operational traffic consisting of predominately VOR/DME equipped aircraft. No special ATC procedures or test procedures were required to obtain satisfactory performance.

In order to provide the proper background and perspective regarding these Loran-C operations, detailed flight test observer records were kept during the tests. An analysis of these records provided insight into the potential problem areas to be expected when introducing Loran-C into normal NAS operations. A total of 58 events occurred which were pertinent to this evaluation. These events were in the areas of pilot/copilot procedures using Loran-C (27), airborne system hardware/software problems (22) and air traffic control (9). No serious airspace deviations occurred due to these 58 occurrences. However, there was a potential for operational problems developing from these occurrences.

OBJECTIVE

2. To verify the navigation accuracy and functional performance of the production version of the AN/ARN-133.

RESULTS

The statistical data indicated that a ±1.0 nm boundary was within the capabilities of the navigator on a two-sigma, 95% probability basis. Using actual aircraft position data obtained from the ARTS III surveillance radar, the following overall performance was obtained:

Error Quality	*Enroute ±2σ Error Values**
Total System Crosstrack Error	*0.60 nm*
Flight Technical Error	*0.19 nm*
Airborne System Error	*0.58 nm*
Alongtrack Error	*0.69 nm*

OBJECTIVE

3. To provide specific data relative to Air Traffic Control operations and pilot workload requirements while transitioning to and from the Northeast Corridor utilizing the Sikorsky, Mack Truck, RCA and New York Airways routes.

RESULTS

Air Traffic Control operations on the spur routes were simplified compared to the Northeast Corridor route due primarily to the lower traffic density encountered. Some difficulties were experienced with other fixed wing traffic not on the spur routes, but no separation problems or route deviations (vectors) were encountered. Pilot workload was acceptable on these short segments even though waypoints were closely spaced and some large angle turns were required. However, a two member crew was used at all times and the flights were flown under visual flight rules.

The track keeping accuracy on the spur routes was comparable to the enroute Northeast Corridor results. The following overall performance was obtained:

Error Quality	*Maximum ±2σ Spur Route Data**
Total System Crosstrack Error	*0.70 nm*
Flight Technical Error	*0.25 nm*
Airborne System Error	*0.70 nm*

**/NOTE/: These ±2σ error values include any ARTS III radar tracking errors.*

In addition to these three primary objectives, the Northeast Corridor operational flights provided interesting results in several other areas. For example, additional Non-Precision Approach data was collected at both ends of the test route. At Boston's Logan International Airport, Loran-C approach data was collected in two ways. First, a series of Loran-C approaches were made and tracked with ARTS III radar similar to the NAFEC approach data tracked by EAIR. Second, an ILS approach was flown and tracked by ARTS III while simultaneously recording the indicated aircraft position from the Loran-C navigator. At Frederick, Maryland near Washington, D.C., there was no ILS. Therefore, one series of approaches were evaluated qualitatively using visual approach techniques. Another type of approach evaluated during the Northeast Corridor flight test program was the Point-in-Space approach (PISA). These approaches were performed at both ends of the corridor as well as during the Spur route testing. This new procedure was evaluated quantitatively and qualitatively during these tests. Finally, preliminary VOR/DME signal coverage data was collected (while navigating with Loran-C). This data was taken to substantiate the availability of VOR/DME signals at the low altitude normally flown by helicopters in the Northeast Corridor. The following paragraphs enumerate the results for these additional test objectives in the Northeast Corridor.

OBJECTIVE

4. To provide additional Loran-C non-precision approach data which will supplement previously acquired AN/ARN-133 and TDL-424 approach data obtained at NAFEC.

RESULTS

Non-precision Loran-C approach data collected at Frederick, Maryland and Boston, Massachusetts substantiated the previous approach data acquired at NAFEC. Total System Crosstrack errors measured during the NAFEC tests varied from 0.26 to -0.38 nm where the minus sign indicates aircraft deviations to the left of the desired track. The data from Boston showed an aggregate error of +0.32 nm and at Frederick a value of -0.25 nm was obtained. These errors were within the range of data taken at NAFEC.

OBJECTIVE

5. To evaluate Loran-C as an approach aid to point-in-space approaches and to unaided helipads.

RESULTS

The operational viability of the point-in-space approach concept was substantiated during this flight test program. Many point-in-space approaches were performed at Boston, Massachusetts; Washington, D.C.; New York City, New York; and during Spur route testing. In

addition, approaches to unaided helipads were flown with acceptable results. The quantitative aggregate data for Total System Cross-track error during these approaches was similar to the non-precision approach data. Two-sigma error quantities ranged from 0.17 nm to 0.33 nm. Although no accuracy criteria is currently specified for point-in-space approaches, the accuracies experienced were acceptable from an operational ATC interface viewpoint. Pilot workload was generally low on these approaches due to the ability to avoid conventional approach path traffic.

OBJECTIVE

6. To acquire preliminary data on VOR/DME signal coverage at low altitudes in the Northeast Corridor.

RESULTS

During the low altitude (500'-2000' AGL) Loran-C Northeast Corridor flights, the pilot was asked to tune in the VORs specified on the published chart and monitor flags and loss of station lock. This qualitative data was collected to determine whether or not any significant VOR/DME signal dropouts would occur at these altitudes. No significant dropouts were experienced during these flights. In two cases, the test aircraft lost lock. However, one was for only a brief 45 second period and the other was below 500 feet AGL during an approach using a non-collocated VOR. Only one station could not be acquired during one flight. Providence VOR had been used previously, but could not be received on the next day's flight.

NAFEC System Accuracy Test Results --

The second major test area was the system accuracy testing performed at NAFEC. This testing was designed to collect accuracy data on the production Loran-C navigator during enroute, terminal area and final approach phases of flight. This data can be used to assess the acceptability of Loran-C as an area navigation system operating within the National Airspace System. To accomplish this assessment, the Loran-C accuracy must be compared to the criteria specified in Advisory Circular 90-45A which specifies "Approval of Area Navigation Systems in the U.S. National Airspace System". This document specifies airspace limits within which the navigation system must operate. These limits may be compared to the measured two-sigma errors in actual aircraft position vs desired aircraft track. The tracking data collected at NAFEC was obtained from the "Extended Area Instrumentation Radar" operating in the beacon tracking mode. Both crosstrack and alongtrack aircraft position data was derived from the actual radar track of the aircraft. The following paragraphs address the two major test objectives and the results obtained from this accuracy evaluation.

OBJECTIVE

1. To supplement the previously acquired Loran-C navigator IFR certification data, for AC 90-45A compliance, for operations in both HH3 and HH52 helicopters.

RESULTS

Overall comparison of measured AN/ARN-133 Total System Accuracy (at NAFEC) compared to AC 90-45A requirements was as follows:

	Crosstrack		*Alongtrack*	
	AC 90-45A	*Measured*	*AC 90-45A*	*Measured*
Enroute	*2.5 nm*	*0.6 nm*	*1.5 nm*	*0.2 nm*
Terminal	*1.5 nm*	*0.5 nm*	*1.1 nm*	*0.6 nm*
Approach	*0.6 nm*	*0.5 nm*	*0.3 nm*	*0.5 nm*

These results show that the production navigator satisfied AC 90-45A crosstrack accuracy requirements for enroute, terminal area and non-precision approach as well as alongtrack accuracy requirements for enroute and terminal area operations. The navigator did not satisfy the alongtrack accuracy requirement for non-precision approaches.

OBJECTIVE

2. To evaluate the production version Loran-C navigator telemetry data link function as a low altitude aircraft surveillance tool.

RESULTS

The telemetry position downlink function worked acceptably as an aircraft surveillance aid. The Loran-C flight path data from the telemetry was overlayed with the precision tracking radar data for comparison. The telemetry position was similar to the radar track and consistently within 0.6 nm of the radar track.

Offshore Test Results --

The third major test area was offshore operations. There were four test objectives to be satisfied which required flights overwater. Three deep probes offshore were performed to demonstrate Loran-C signal availability accuracy and repeatability during long range overwater missions. The existence of a Loran-C signal anomaly along the coastline had been hypothesized. The coastline Loran-C performance was investigated both at dusk and at dawn. Ship/Helo rendezvous tests were performed to determine if any improvements in current procedures could be achieved using Loran-C. Finally, oil rig tests were performed to verify the ability of Loran-C to accurately guide an aircraft to rigs in various cluster densities and to illustrate Loran-C repeatability accuracy for USCG surveillance purposes. The following paragraphs summarize the offshore test results.

OBJECTIVE

1. To demonstrate operation of the Loran-C navigator during long range (100-200 nm) overwater missions.

RESULTS

Deep probe data was collected during three separate flights. Distances offshore for these flights were 150 nm, 160 nm and 200 nm. Data was collected on both the 9960 and 9930 Loran-C chains during these tests. Precision tracking radar coverage extended offshore to approximately 100 nm. Loran-C airborne position data was obtained for the duration of each flight. Total System Crosstrack errors for these flights were very small. These errors ranged from -0.02 nm to -0.25 nm on the 9930 chain and from -0.07 nm to +0.10 nm on the 9960 chain. Flight Technical Error during these long range flights was consistently less than 0.10 nm. Alongtrack Loran-C errors ranged from +0.30 nm to +0.32 on the 9930 chain and -0.38 nm to -0.42 nm on the 9960 chain. No significant ATC coordination, communication or navigation problems occurred during any of the deep probe flights.

OBJECTIVE

2. To investigate the potential Loran-C signal anomaly peculiar to coastline overland/overwater transitioning.

RESULTS

Based on a detailed analysis of actual aircraft tracking data, lat/lon Loran-C data and crosstrack deviation/distance-to-go information displayed and recorded in the cockpit, no significant coastline signal anomalies were discovered.

OBJECTIVE

3. To evaluate the Loran-C navigator as an approach aid to the flight decks of ships and offshore oil rigs.

RESULTS

Several types of ship/helo rendezvous procedures were evaluated during these tests. Compared to conventional timed procedure turns, the Loran-C navigator reduced workload and improved accuracy during ship/helo rendezvous. A revised procedure was developed which could be used as a replacement for current procedures for Loran-C equipped aircraft.

The Loran-C also provided accurate and repeatable guidance to offshore oil rigs regardless of oil rig cluster density. (See next paragraph).

OBJECTIVE

4. *To verify that the previously acquired prototype Loran-C search and rescue and surveillance accuracies can be attained by the production navigator.*

RESULTS

The results of the accuracy and repeatability testing of the Loran-C navigator were analyzed using 2 d_{rms} statistics. (2 d_{rms} defines an ellipse where there is a 95.4% to 98.2% probability of locating a target within an associated 2 d_{rms} error in feet, for each oil rig or all rigs combined). The 2 d_{rms} errors ranged from 378.9' to 1698.3' for the rigs tested. These values were obtained during a stabilized hover at a location approximately 60' laterally from the rig and 20' vertically. These accuracies were obtained using the 9930 chain in the Gulf of Mexico since the 7980 chain was not operational during the test period.

In addition to the surveillance tests, the production navigator repeated some of the search and rescue patterns originally evaluated with the prototype navigator. The production Loran-C navigator verified the accuracy and repeatability previously obtained.

1.5 CONCLUSIONS

The major conclusions from the operational flight test evaluation of the production AN/ARN-133 Loran-C navigator are summarized in this section. These conclusions are, by intent, qualitative and interpretive in nature. The quantitative results from which these conclusions were reached have been summarized in Section 1.4 and are discussed in Section 5.0 of this report.

In the Northeast Corridor operational testing, the production navigator was evaluated for enroute, non-precision approach and point-in-space approach capabilities. The AN/ARN-133 performance was found to be acceptable from an operational viewpoint for all three flight regimes. That is, the navigator's functional performance was acceptable from both the pilot's viewpoint and an ATC interface viewpoint. The accuracy data collected during the Northeast Corridor tests was essentially the same as the larger, more precise accuracy data base collected at NAFEC. For this reason, it was concluded that the AN/ARN-133 was acceptable for enroute, and point-in-space approaches.

From an operational viewpoint, the production navigator did not cause any significant problems in interfacing with the predominantly VOR/DME traffic in the Northeast Corridor environment. Pilot workload and ATC operations were acceptable in both enroute corridor operations and the transition or spur routes to and from the corridor. During the Loran-C testing, specified VOR/DME reference facilities were tuned in and signal coverage was found to be adequate even down to 500' AGL.

Data from the NAFEC System Accuracy testing showed that the production Loran-C navigator made by the Teledyne Systems Company satisfied AC 90-45A accuracy requirements for enroute and terminal area in both alongtrack and crosstrack directions. For non-precision approaches, the navigator satisfied the crosstrack accuracy requirements, but did not satisfy the alongtrack accuracy requirement.

In the additional telemetry testing performed at NAFEC, the Loran-C navigator's telemetry function was acceptable as an aircraft surveillance aid.

The Offshore Test results showed that the AN/ARN-133 performed acceptably for USCG surveillance, ship/helo rendezvous and search and rescue missions. The navigator accuracy was found adequate for approaches to offshore oil rigs and to unaided helipads. No accuracy problems, functional problems or operational problems were encountered that would preclude acceptance of the production navigator for USCG missions.

2.0 INTRODUCTION

The implementation and acceptance of Loran-C as an airborne navigation system suitable for the missions of the United States Coast Guard, as well as for operations by the Coast Guard and other civil users within the National Airspace System, is addressed in this report. This acceptance requires that several accuracy, repeatability, operational suitability and NAS compatibility questions be resolved. In order to answer these questions and to document the performance of the AN/ARN-133 navigator, a comprehensive evaluation program was developed. This document describes the detailed results of the airborne Loran-C navigator tests performed by the Coast Guard to support the evaluation program.

2.1 BACKGROUND

The flight test program was performed from June 1978 through January 1979. The testing included verification of system accuracy, operational suitability testing in the Northeast Corridor, accumulation of additional data for IFR certification, long range overwater testing, and evaluation of Loran-C as a non-precision approach aid to both fixed and moving targets at sea.

The accuracy data was compiled during testing performed at the National Aviation Facilities Experimental Center (NAFEC) at Atlantic City, New Jersey and during the operational Northeast Corridor flights. These data were compared to and combined with the data previously collected on the prototype TDL-424 airborne Loran-C navigator.

Operational data was obtained and procedural questions were addressed primarily using the Northeast Corridor test results. However, these results were complemented by results from the overwater/overland transition data, deep probes over the Atlantic Ocean and from operations in the Gulf of Mexico during the ship rendezvous and oil rig testing.

Both the accuracy data and the operational results were dependent on position information obtained from radar tracking and the airborne navigator lat/lon position information. These data were supplemented by detailed flight test observer logs as well as debriefing information obtained during the tests. The primary measure of performance was total system crosstrack error as measured with the tracking radar. This analysis was supported by examination of airborne flight technical error and airborne navigation equipment crosstrack error. A detailed description of the analysis techniques is presented in Appendix C.

2.2 PURPOSE OF THE TESTS

The objectives of this "Airborne Evaluation of the Production AN/ARN-133 Loran-C Navigator" can be summarized in three statements: first, to demonstrate the degree of operational and functional compatibility of Loran-C navigation in the current VOR/DME environment of the Northeast Corridor; second, to verify that the production version of the Loran-C navigator can duplicate the accuracy and repeatability established during

the previous flight testing of the prototype system; third, to demonstrate offshore operational applications and capabilities of Loran-C for both the Coast Guard and other users' missions. Each of these primary purposes is expanded and discussed in depth in Section 3.0.

2.3 ORGANIZATION OF THE REPORT

The results of the AN/ARN-133 evaluation are presented in the remainder of this report. Section 4.0 provides an overview description of the tests including number of flights and nautical miles flown for each test area. A detailed equipment summary, a flight profile description for each specific test performed, and an enumeration of the detailed steps involved in test data acquisition and reduction are presented in Appendices A, B and C respectively. Section 5.0 presents and documents the specific AN/ARN-133 test results obtained in three major areas:

1) Northeast Corridor Operational Testing

2) NAFEC System Accuracy Testing

3) Offshore Testing

Section 6.0 extracts the primary results documented in each of these three major areas and summarizes the quantitative data. Section 7.0 presents the operational interpretation of the flight test results in the form of major qualitative conclusions for each of the three areas. All of the quantitative and qualitative data discussed in Section 5.0, 6.0 and 7.0 is related explicitly and organizationally to the stated program objectives from Section 3.0.

3.0 DETAILED TECHNICAL OBJECTIVES

The flight test evaluation of the AN/ARN-133 airborne Loran-C navigator was designed to satisfy twelve overall objectives. These can be summarized as follows:

1) To demonstrate operation of the Loran-C navigator in the Northeast Corridor operational ATC environment.

2) To verify the navigation accuracy and functional performance of the production version of the AN/ARN-133.

3) To provide data specific to Air Traffic Control operations and pilot workload requirements while transitioning to and from the Northeast Corridor utilizing the Sikorsky, Mack Truck, RCA and New York Airways Routes.

4) To provide additional Loran-C non-precision approach data which will supplement previously acquired AN/ARN-133 and TDL-424 approach data obtained at NAFEC.

5) To evaluate Loran-C as an approach aid to point-in-space approaches and to unaided helipads.

6) To acquire preliminary data on VOR/DME signal coverage at low altitudes in the Northeast Corridor.

7) To supplement the previously acquired Loran-C navigator IFR certification data, for AC 90-45A compliance, for operations in both HH3 and HH52 helicopters.

8) To evaluate the production version Loran-C navigator telemetry data link function as a low altitude aircraft surveillance tool.

9) To demonstrate operation of the Loran-C navigator during long range (100-200 nm) overwater missions.

10) To investigate the potential Loran-C signal anomaly peculiar to coastline overland/overwater transitioning.

11) To evaluate the Loran-C navigator as an approach aid to the flight decks of ships and offshore oil rigs.

12) To verify that the previously acquired prototype Loran-C Search and Rescue and surveillance accuracies can be attained by the production navigator.

The first six objectives were specific evaluation elements of the operational test plan designed for the Northeast Corridor. Objectives seven and eight were addressed using NAFEC test results from both the production and prototype Loran-C navigators, Finally, objectives nine through twelve were included in the offshore testing performed in the coastal waters off of Atlantic City, New Jersey

and in the Gulf of Mexico. In order to provide a more thorough understanding of each of these objectives, the following paragraphs provide additional background information used in designing the evaluation program.

3.1 NORTHEAST CORRIDOR OPERATIONAL TESTING

The data collected in the corridor connecting Washington, D.C. with Boston, Massachusetts consisted of enroute, transition routes and final approach testing. Both technical and operational test objectives were associated with this portion of the test program. As stated in objective number one, the flight test evaluation of the AN/ARN-133 navigator presented an opportunity to evaluate the production version of the airborne Loran-C navigator in an operational ATC environment. The accuracy data acquired on this version was used to supplement previous data obtained on the prototype TDL-424 in enroute, terminal and approach operations at NAFEC, surveillance operations, and search and rescue (SAR) operations. Loran-C navigator accuracy, pilot workload and ATC compatibility were documented during the AN/ARN-133 test in comparison to applicable TDL-424 test results. In this manner, the changes and improvements currently available in the production Loran-C navigator can be assessed directly. For example, the production navigator has significantly automated the search and rescue data input workload for both creeping line and sector searches. This automated technique will be compared to the previous SAR data flown manually with the TDL-424. Other features incorporated in the production navigator will be similarily evaluated.

A second important element of the AN/ARN-133 evaluation was the operational evaluation of Loran-C navigation in the high density area of the Northeast Corridor. This portion of the testing satisfied several sub-objectives which included satisfying airspace and ATC operating requirements, demonstration of the compatibility of Loran-C navigation with other aircraft predominantly using VOR/DME navigation and accurate transitioning to and from the Northeast Corridor routes.

3.1.1 Enroute

The primary purpose of the AN/ARN-133 enroute NEC data collection effort was to obtain airspace utilization and Loran-C system accuracy statistics in an operational environment. This enroute data on the production navigator was acquired to develop operational statistics for enroute accuracy determination that would be comparable to the limited data base developed enroute between Cape May and NAFEC in New Jersey. Data was taken in the NAFEC area on both the production and the prototype Loran-C navigators. Both of the navigators have been tested enroute in the HH52 aircraft. In addition, the production navigator collected enroute data in the HH3 aircraft over the Northeast Corridor routes. The enroute data base covers the altitude spectrum from 500 feet to 4500 feet.

3.1.2 Transition (Spur) Routes

The transition, or spur, routes which are currently used to fly to or from the Northeast Corridor were evaluated to satisfy objective number three. These routes were much shorter in length and contained larger angle turns than the NEC enroute segments. These routes were flown at low altitudes to compare Loran-C coverage to VOR/DME coverage in the Northeast Corridor. This data was used to satisfy objective number six. These routes also provided procedures data and operational compatibility data in the high density NEC environment below normal surveillance radar coverage.

3.1.3 Final Approach Testing

Objectives four and five were addressed by collecting final approach data using the production navigator. Two types of approach procedures were evaluated. Non-precision approach (NPA) data was collected for a direct comparison with prototype data previously obtained. NPA data was collected at Frederick, Maryland and Boston, Massachusetts. The Frederick, Maryland location provided NPA data on a Loran-C baseline. The Boston NPA data was for an airport located very close to one secondary and very far from the other.

The second type of final approach testing was the "point-in-space approach" (PISA). This is an approach to a point away from the primary traffic flow and the approach course to the active runway. This point should be located such that when minimum descent altitude has been reached, the pilot can continue the approach to the destination airport under visual flight rules. PISA data was collected in response to objective five at Boston, New York and Washington, D.C.

3.2 NAFEC SYSTEM ACCURACY TESTING

The data collected on the production Loran-C navigator at NAFEC was used to satisfy objectives seven and eight. That is, specific routes previously flown using the prototype navigator in the HH52 aircraft were reflown using the production navigator. Both the HH52 and HH3 aircraft were flown on these routes. Enroute, terminal maneuvering and non-precision approach data was collected. This data was directly comparable with the prototype results. The precision tracking radar facility (see Appendix C) at NAFEC was used to determine airspace requirements, flight technical error and Loran-C airborne navigator errors. This complete data set (prototype and production) can be used to generate a set of Loran-C data suitable for submission to the FAA in compliance with AC 90-45A requirements.

In addition to this Loran-C accuracy data base, the production navigator was used to demonstrate a telemetry data link function. This test was flown at NAFEC to illustrate possible applications (or integration) with current ATC procedures for the offshore oil rig operators. The Loran-C telemetry provides a plot of aircraft present position below normal surveillance radar coverage which could be used both onshore and offshore.

3.2.1 Review of Prototype Testing

Previous testing of the prototype TDL-424 Loran-C navigator provided total system accuracy, flight technical error and airborne equipment error data in the airspace in and around NAFEC. This data was flown solely in an HH52 aircraft. Multiple flights were flown over enroute, terminal and final approach route segments. These previous tests were designed to provide a matrix of data suitable for demonstration of compliance with the certification criteria of AC 90-45A In general, the prototype data demonstrated "compatibility of a Loran-C navigation system with both present and planned area navigation routes and procedures for enroute, terminal and final approach operations" (Report No. CG-D-9-77). The demonstrated accuracy of the prototype was compared explicitly to AC 90-45A requirements in the referenced report. The primary purpose of the production navigator testing was to validate the prototype data using the production unit and to expand the data base to include both HH52 and HH3 aircraft. The expanded data base was designed to verify that the production navigator was at least as accurate as the prototype unit. Due to the large data base previously collected on the prototype, this verification was performed using a limited number of enroute, arrival and departure flights for the two aircraft. However, in the final approach area, the data base was greatly expanded.

Prototype non-precision approach data was collected solely using runway 04, using the various navigator operating modes of non-updated, updated and time-difference navigation. The production navigator was tested using all three active runways and performing NPA's to both ends of each runway. The purpose of this was to demonstrate, in a fixed Loran-C chain geometry, the impact of Loran-C bias errors on NPA accuracy data. The corollary NPA data using varying chain geometry was previously discussed in Sections 3.1.3.

3.2.2 Specific Production Loran-C System Accuracy Test Objectives

The testing performed at NAFEC using the production AN/ARN-133 Loran-C navigator was designed to satisfy several specific objectives. These objectives can be summarized as follows:

1) To obtain total system accuracy, flight technical error and airborne equipment error data compatible with the prototype data base and suitable for compliance with AC 90-45A accuracy criteria.

2) To demonstrate the applicability of the Loran-C navigator for reduced route width flying on specially designed routes (accuracy data from precision tracking radar required).

3) To expand the non-precision approach data acquired during prototype testing.

4) To demonstrate that previous Loran-C data, taken in a small and relatively slow HH52, can be validated in the larger and faster HH3.

The extensive system accuracy data base collected at NAFEC represents the actual performance of the installed navigator as accurately as it can be defined. This is due to the use of the precision tracking radar used for ground truth. Other system accuracy data acquired using ARTS III and IA tracking can be used qualitatively to estimate whether or not the aircraft remains within specified route width, however, the ARTS data should not be interpreted as actual Loran-C performance due to the angular error characteristics of the relatively lower quality ARTS surveillance radar. By using a combination of the precise quantitative Loran-C performance measured at NAFEC and the qualitative performance measured elsewhere using ARTS radar, it is possible to estimate Loran-C acceptability as an airborne navigator in other Loran-C chain geometries, but not to precisely quantify that performance.

3.2.3 Telemetry Tracking

The primary purpose of the telemetry tracking tests performed at NAFEC was to demonstrate this unique feature of the production navigator. However, in addition to demonstrating the ability to obtain surveillance data from the aircraft equipped with Loran-C, the NAFEC environment also provided a relative accuracy comparison between the telemetered position data and the actual aircraft position as determined using the precision tracking radar. Therefore, a secondary purpose of this test was to assess the basic accuracy of the telemetry data and to determine its suitability from an aircraft surveillance (ATC) viewpoint.

3.3 OFFSHORE TESTING

The offshore testing performed with the production AN/ARN-133 navigator was performed in the Gulf of Mexico as well as in the Atlantic Ocean offshore from Atlantic City, New Jersey. Five primary test areas were investigated. These included a deep probe out to 200 nm offshore, a creeping line pattern along the coastline to evaluate possible Loran-C signal anomalies, a ship-helo rendezvous evaluation, oil rig tests and search and rescue tests. This section describes the detailed test objectives and data collection efforts in these five areas of interest.

3.3.1 Deep Probe Overwater Tests

The principal objective of the Deep Probe Overwater Tests was to demonstrate operation of the Loran-C navigator during long range overwater missions. This data is directly applicable to the U.S. Coast Guard surveillance mission. The accuracy and repeatability of Loran-C in this environment was determined by using the NAFEC precision tracking radar out to a distance of 100 nm offshore. The departure from and return to the 100 nm point over a preprogrammed Loran-C course will provide both quantitative and qualitative data for this important USCG mission. A second objective of these tests was to determine and define any operational ATC interface problems in the overland/overwater transition. This data should provide interesting preliminary information for the FAA/ATC community in an area where the offshore oil industry is just developing.

3.3.2 Coastline Signal Anomaly Testing

These tests were performed by traversing the New Jersey Coastline in a creeping line or ladder type pattern while flying approximately five nautical miles overland and five overwater. The purpose of this pattern was to investigate a postulated coastline Loran-C signal anomaly due to the difference in the velocity of signal propogation overland vs. overwater. The potential impact of this coastline signal anomaly was of interest from both total system accuracy and flight technical error viewpoints. In addition, the possible effect of such an anomaly on ATC procedures and aircraft separation in a mixed VOR/DME and Loran-C environment was of interest.

3.3.3 Ship/Helo Rendezvous Tests

The main purpose of this phase of the Loran-C testing was to determine if an improvement in ship/helicopter rendezvous procedures could be attained through utilization of the AN/ARN-133 navigator. The amount of testing was deliberately limited and no previous flight training was provided the flight crew. The conventional ship/helo rendezvous procedure was used initially and then several alternative AN/ARN-133 navigation techniques were tried to reduce rendezvous workload, improve accuracy and decrease time to rendezvous. Procedures were developed/modified in real time as well as during the post flight debriefing. This data demonstrated the advantages of using the Loran-C navigator as an approach aid to ships.

3.3.4 Oil Rig Tests

The oil rig testing was performed to demonstrate the further utility of Loran-C as an approach aid to oil rigs. An area coverage navigation system like Loran-C is needed in the offshore oil industry especially in the area outside of normal VOR/DME coverage (40 nm) or where no VORTAC station is available. The Loran-C navigator is capable of not only establishing the aircraft on the proper course direct to the oil rig from the shoreline, but also in providing guidance to a waypoint designated as a final approach fix or missed approach waypoint. The purpose of these tests were to determine the accuracy and the repeatability of the Loran-C guidance in the offshore environment of the Gulf of Mexico where the population and density of oil rigs is quite high. The data collected during these tests of the production navigator will also provide a comparison with the prototype data obtained in Delaware Bay and offshore from Cape May, New Jersey.

3.3.5 Search and Rescue

The SAR tests were performed primarily to verify that the production navigator performed the creeping line and sector search patterns at least as well as the prototype unit. In addition, software changes were made to the production unit as a result of the previous testing. These changes were made to reduce the pilot input workload and to automate the initial entry, execution, departure and return to search patterns. For this reason, the production Loran-C SAR tests were used to check the new software as well as the tracking accuracy. Also, the ability of

the production navigator to proceed to an impromptu waypoint defined by a distance and bearing from a previously stored waypoint was evaluated during these SAR tests. Finally, the parallel offset and present position direct-to a fix modes of operation were demonstrated at the completion of each SAR during the return flight to Cape May Air Station.

4.0 DESCRIPTION OF THE TESTS

The flight test evaluation of the airborne AN/ARN-133 Loran-C navigator was performed between 1 June 1978 and 19 January 1979. 93 hours of flying were accomplished during this test period. The 93 hours were divided between U.S. Coast Guard test objectives (61 hours) and Federal Aviation Administration Loran-C test objectives (32 hours). As described during the discussion of the test objectives (Section 3.0), the three primary areas of testing were Northeast Corridor (53 hours), NAFEC System Accuracy Tests (16 hours) and Offshore Tests (24 hours). As can be seen by the distribution of flight test hours, the primary emphasis of this flight test program was an operational evaluation of the production Loran-C navigator in the Northeast Corridor environment. The intent of this testing was to demonstrate that an aircraft equipped with Loran-C could integrate with conventional VOR/DME traffic and satisfactorily perform ATC procedures while maintaining a desired track within the reduced route width specified for the Northeast Corridor (±2 nm). Although precision radar tracking data was not available for the entire corridor, it was felt that by using ARTS III radar data combined with the inflight observations of the pilot, copilot and flight test observer and substantiated by the lack of any significant ATC operational problems, a suitable demonstration could be accomplished. It is a well known fact that the ARTS III radar data is intended for ATC surveillance purposes only. However, to the extent that it is used for aircraft separation in daily NAS operations, it can also be used as a suitable estimate for actual aircraft position within a ±2 nm route width. To this end, statistical mean and two-sigma aircraft total system cross-track errors were calculated using the ARTS III radar data. In addition, a calibration check of the ARTS III was made in the area of overlapping EAIR and Philadelphia ARTS III radar coverage. This calibration provided insight into the accuracy of the ARTS III data and how the data should be utilized. This data should not be interpreted as precise position information, but rather as a quantitative verification that the Loran-C navigator was able to perform within the specified route width limits. This data can, however, be compared with the precision tracking data obtained during the NAFEC System Accuracy Testing. The ARTS III data can also be used to obtain a qualitative assessment of relative Loran-C errors under varying station geometries as the corridor is traversed from Washington to Boston. Once again, a careful comparison is necessary to insure that ARTS III facility coverage is adequate for each point of comparison covered by a different facility.

The 16 hours of NAFEC System Accuracy testing represent a limited data set which was collected primarily to validate prototype results and to expand the system accuracy data base to include the HH3 aircraft as well as the HH52.

The 24 hours of Offshore testing was divided between the five test areas previously defined in Sections 3.3.1 through 3.3.5.

Another way of quantifying the flight test activity during this operational evaluation is by the total number of nautical miles flown

for each type of testing performed. This quantification is interesting for two reasons. First, it is one method of presenting data for certification purposes when discussing enroute, terminal and final approach accuracy. Second, this subdivision allows an easy interpretation of how the production navigator data base integrates with the previously acquired prototype data (Reference 2). Table 4.1 summarizes the total number of nautical miles flown using the production AN/ARN-133 airborne Loran-C navigator. The data is categorized by the three major test areas which will be discussed throughout this report. The enroute, terminal and offshore testing is shown by total nautical miles flown while the final approach data shows the number of each type of approach, which is more meaningful. It is significant to note that over 4100 miles of flying in the operational environment of the Northeast Corridor was successfully accomplished. This large amount of flight test activity, which was performed at altitudes from 500 feet to 4500 feet, did not cause any significant operational problems from either the ATC or the flight crew's viewpoint. That is, no deviations from the planned route of flight occurred which caused either an ATC problem or an aircraft guidance problem. The actual tracks flown during this 4133 nm of testing will be shown and discussed in Section 5.0. None of these tracks exceeded the ±2.0 route width specified for the Northeast Corridor. As with all flight testing, there were both ground and airborne data recording, data retrieval and data processing problems which limited the analysis to less than the 4133 nm actually flown. The operational reasons for the data dropouts, as well as the amount and quality of the actual data collected, will be discussed in depth in Section 5.0.

The production AN/ARN-133 data base collected at NAFEC to evalute navigator system accuracy was much smaller than the Northeast Corridor data base. One hundred eighty five nautical miles of enroute and 348 miles of terminal data were collected to supplement the prototype TDL-424 NAFEC test results. Table 4.2 shows a comparison of the prototype and production programs which illustrate how the two data bases integrate.

It is important to note that a significant number of additional non-precision approaches were flown with the production navigator (40 vs 18). These were flown to obtain Loran-C bias error data for all runway headings at NAFEC (04, 08, 13, 22, 26, 31). The prototype non-precision approach data base was flown solely to runway 04.

It is also interesting to aggregate and compare all final approach data collected. Table 4.3 shows a summary of both point-in-space (PISA) and non-precision (NPA) approach data.

It can be seen that PISA data was concentrated in the Northeast Corridor; while NPA accuracy data was concentrated at NAFEC with over half of the NPA data being taken on the production navigator. However, the 18 prototype approaches at NAFEC are sufficient to verify that both navigators behaved similarly in the final approach area. Similarly, the 12 production approaches performed in the Northeast Corridor indicated NPA performance similar to the NAFEC data at two different Loran-C geometries.

Table 4.1 Production Loran-C Navigator Flight Test Program Summary

I.	NORTHEAST CORRIDOR OPERATIONAL TESTING	
	Enroute Distance Flown	4133 nm
	Number of Approaches Flown	
	Point-in-Space	43
	Non-Precision	12
II.	NAFEC SYSTEM ACCURACY TESTING	
	Enroute Distance Flown	185 nm
	Terminal Distance Flown (6 SIDs/6 STARs)	348 nm
	Number of Approaches Flown	
	Point-in-Space	0
	Non-Precision	40
III.	OFFSHORE TESTING	
	Deep Probe Overwater (3 flights)	989 nm
	Coastline Signal Anomaly	311 nm
	Ship/Helo Rendezvous (12 approaches)	48 nm
	Oil Rig Tests (9 approaches)	280 nm
	Search and Rescue Test	270 nm
	OFFSHORE TOTAL ----------------------	1898 nm

Table 4.2 Summary of Production and Prototype System Accuracy Testing at NAFEC

AIRSPACE	PRODUCTION	PROTOTYPE	TOTAL
Enroute Distance Flown	185 nm	268 nm	453 nm
Terminal Distance Flown	348 nm	362 nm	710 nm
NUMBER OF APPROACHES FLOWN			
Point-in-Space	0	0	0
Non-Precision	40	18	58

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Table 4.3 Production and Prototype Loran-C Final Approach Testing

APPROACH TYPE	NAFEC PROTOTYPE	NAFEC PRODUCTION	NEC PRODUCTION	TOTAL
Number of PISAs	0	0	43	43
Number of NPAs	18	40	12	70

Finally, it is important to understand the scope of Loran-C offshore flight testing and the breakdown between production and prototype data collection. Table 4.4 presents this information. The total number of offshore miles flown is seen to be 2681, which represents a significant amount of overwater operations. Table 4.4 shows that production Loran-C data was taken to validate prototype search and rescue performance and to test the repeatability of Loran-C for surveillance purposes (oil rig hover tests). The new offshore data collected by the production navigator was in the areas of long overwater flights (>200 nm), the coastline signal anomaly investigation and the examination of alternative Ship/Helo rendezvous procedures.

Table 4.4 Summary of the Offshore Loran-C Data Base

TYPE OF TEST	NUMBER OF FLIGHTS		DISTANCE COVERED	
	PROTOTYPE	PRODUCTION	PROTOTYPE	PRODUCTION
Deep Probe Overwater	0	3	0	989
Coastline Signal Anomaly	0	2	0	311
Ship/Helo Rendezvous	0	12	0	48
Oil Rig Tests	2	2	132	280
Search and Rescue	7	2	651	270
Sub-Totals	9	21	783	1898
TOTALS	30		2681	

5.0 DISCUSSION OF RESULTS AND ANALYSIS

The purpose of this section is to provide the detailed tabular and graphical data necessary to support the results, conclusions and recommendations of this report. The data discussed herein was collected during the operational flight test evaluation of the airborne AN/ARN-133 Loran-C navigator. This evaluation was performed between June 1978 and January 1979. Table 5.1 provides a chronological summary of the data collection effort including the aircraft type, the number of hours flown, and the status of all data collected. The details presented in this section represent the results of a comprehensive review of the specific data collected on the ground, and in the air, regarding actual aircraft position, Loran-C indicated position, flight technical error, pilot workload, operational navigation problems and Loran-C equipment problems.

For ease of correlation with the test objectives and other sections of this report, these results are organized according to the three major data collection activities. Section 5.1 presents the results of the operational testing performed in the Northeast Corridor. This data includes enroute, transition or spur routes and final approach testing. Section 5.2 discusses the NAFEC system accuracy test results for three airspace regions —— enroute, terminal and approach. This section also presents a master summary of all data acquired for AC 90-45A compliance, both on the prototype and production navigators. Finally, Section 5.3 summarizes all offshore Loran-C data collected during this evaluation. This data includes deep probe tests, coastline signal anomaly tests, ship/helo rendezvous tests, oil rig tests and Search and Rescue tests.

5.1 NORTHEAST CORRIDOR OPERATIONAL TESTING

The purpose of the operational testing in the Northeast Corridor was to demonstrate the Loran-C navigator system as an area navigation system suitable for operation on charted IFR routes and for integration in the operational environment of the National Airspace System. The demonstration flights consisted of flying an experimental helicopter test route, both northbound and southbound, from Boston to Washington, D.C. The unique aspects of this route were its reduced route width of ±2 nm compared to the typical ±4 nm enroute protected airspace in the NAS and its low MEAs (from 1500' to 2000' MSL). The data collected on these routes is presented in Section 5.1.1 In addition to the enroute flights on the Northeast Corridor, test data was collected over several transition, or spur, routes used to depart from, and transition to the corridor. This data is summarized and discussed in Section 5.1.2.

5.1.1 Enroute NEC Results

The enroute data collected during these tests was processed to achieve three overall program goals. First, to determine the acceptability of Loran-C navigation accuracy, a composite plot of the actual aircraft tracks was constructed. The intent of this plot was to illustrate the repeatability of the Loran-C navigator on both northbound and southbound routes

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Table 5.1 AN/ARN-133 Chronological Program Summary

DATE	AIRCRAFT	ROUTE	HOURS FLOWN	DATA STATUS						
				AIRBORNE		TRACKING			OBSERVER LOGS	
				GOOD	NO GOOD	SITE	GOOD	NO GOOD	GOOD	NO GOOD
6/1/78	HH3	Deep Probe	2.5		X	EAIR	X		X	
6/2/78	HH3	Deep Probe	3.2	X		EAIR	X		X	
6/13/78	HH52	SAR	2.0	X		EAIR	X		X	
7/6/78	HH52	NAS	2.6	X		EAIR	X		X	
7/10/78	HH52	NAS	2.5	X		EAIR	X		X	
7/11/78	HH52	SAR	1.8	X		EAIR	X		X	
7/20/78	HH52	Oil Rig Test	1.0	X		None Req.			X	
7/21/78	HH52	Oil Rig Test	1.5	X		None Req.			X	
8/3/78	HH52	Oil Rig Test	1.6	X		None Req.			X	
10/19/78	HH52	Ship/Helo Rendez	2	X		None Req.			X	
11/1/78	HH3	NEC South	3.3		X	BOS NAS BDL NY PHL BAL DCA	X X Short X X	X None Req.	X	
11/2/78	HH3	NEC, DCA-NAFEC	1.6		X	DCA BAL PHL	X X	None Req.	X	
11/3/78	HH3	NAFEC Final App. Test	1.3	X		EAIR	X		X	
11/5/78	HH3	NEC South, and North to NAFEC	4.8	X		BOS NAS BDL NY PHL BAL DCA	Too Low X X S,N* N S	X X	X	
11/6/78	HH3	NAFEC Final App. Test	2.6	X		EAIR	X		X	
11/7/78	HH3	Deep Probe	3.9	X		EAIR	X		X	
11/8/78	HH3	NAS	2	X		EAIR	X		X	
11/9/78	HH3	NEC, NAFEC-OTIS	3.1	X		EAIR PHL NY BDL NAS BOS	X (EAIR) X X X	X X	X	

/NOTE/ *Southbound and Northbound

Table 5.1 AN/ARN-133 Chronological Program Summary (Continued)

DATE	AIRCRAFT	ROUTE	HOURS FLOWN	DATA STATUS						
				AIRBORNE		TRACKING			OBSERVER LOGS	
				GOOD	NO GOOD	SITE	GOOD	NO GOOD	GOOD	NO GOOD
11/14/78	HH52	NEC,Cape May	3.1	X		PHL	X		X	
		To BOS				NY	X			
					X	BDL	X			
						NAS	X			
						BOS		X		
11/15/78	HH52	NEC, South to	1.6	X		BOS	X		X	
		Brainard Fld.				NAS	X			
						BDL		X		
11/16/78	HH52	Sikorsky Spurs	2.8	X		BDL	X	Runsout	X	
						NAS		X		
11/20/78	HH52	RCA Spurs	2.9	X		PHL	X		X	
12/5/78	HH52	NEC, Cape May	3.8	X		PHL	X		X	
		To BOS; Sikorsky				NY		X		
		App. To BOS.				BDL	X			
						NAS	X			
						BOS	X			
12/6/78	HH52	BOS Final	1.3	X		BOS	X		X	
		App. Test								
12/6/78	HH52	NEC, South and	3.9	X		BOS	X		X	
		Sikorsky Spurs				NAS	X			
		To Bridgeport				BDL	X			
12/7/78	HH52	NEC, South from	4.1	X		BDL		X	X	
		MUSIK to FLOPP:				NY	X			
		Sikorsky App/Dept								
		To JFK, LGA;								
		NY Airways Spurs								
12/8/78	HH52	Allentown Spur	2.8	X		NY		X	X	
						PHL	X	Dropouts		
12/18/78	HH52	Coastline Signal	2.9	X	1/2	EAIR	X		X	
		Anomaly Test								
		Dawn								
12/18/78	HH52	NAFEC Final	2.8	X		EAIR	X		X	
		App. Test								
12/19/78	HH52	PHL/EAIR	2.9	X		EAIR	X		X	
		Correlation				PHL	X			
		Allentown Spur				NY	X			
2/19/78	HH52	NEC, South	1.5	X		PHL	X		X	
		From SLOAN				BAL	X			
		To DCA				DCA		None Req.		
1/15/79	HH52	NEC, North	3.2		X	EAIR	X		X	
		Cape May,NAFEC				PHL	EAIR	X		
		JONNS,BOS				NY		X		
						BDL		X		
						NAS	X			
						BOS		X		
1/16/79	HH52	NEC, South	4.8		2/3	BOS		X	X	
		BOS-DCA				NAS	X			
						BDL		X		
						NY	X			
						PHL		X		
						BAL		X		
						DCA		Wrong Tape		
1/18/79	HH52	Frederick Final	0.9	X		DCA	X	Dropout	X	
		App. Test				BAL		X		
1/18/79	HH52	NEC, North	1.9	X		DCA	X		X	
		BAL to JONNS				BAL		X		
						PHL	X			
1/19/79	HH52	Coastline	2.2	X		EAIR	X		X	
		Signal Anomaly								
		Test — Dusk								

(43)

and to examine the ability of the Loran-C equipped aircraft to stay within the specified ±2 nm route width for this route. Second, statistics were generated for Total System Cross Track Error (TSCT), Flight Technical Error (FTE), Airborne System Error (ASE) and Alongtrack Error (ATE). These statistics were of interest for comparison with the NAFEC system accuracy data. It was recognized that the ARTS III and IA surveillance radar had insufficient tracking accuracy to provide compliance data. However, these statistics should provide a quantitative feel for the approximate magnitude and the worst case Loran-C system accuracy numbers (since ARTS III and IA errors are combined with Loran-C navigation errors for the data analyzed). Third, a detailed operational problem assessment was made of observer's logs, pilot comments and ATC problems encountered.

A. OVERALL PERFORMANCE

Figure 5.1 shows the composite aircraft tracks for both HH52 and HH3 helicopters. For ease of interpretation this figure is divided into two parts. Figure 5.1.A shows the Washington, D.C. to New York, N.Y. data. Figure 5.1.B shows the New York, N.Y to Boston, Massachusetts data. The tracks were flown from November 5, 1978 to January 18, 1979. An inspection of Figure 5.1 shows that for all the flights performed, the test helicopters stayed well within the specified ±2 nm route width. A closer examination of the figure also shows that no significant track deviations occurred either at turns or due to data input workload. (The AN/ARN-133 stores only nine waypoints and the Southbound corridor route has 22 while the Northbound route has 20). These tracks, when viewed as a group, lead to the conclusion that the test aircraft never strayed outside of ±1.0 nm from the desired track centerline.

The ARTS facilities used to obtain the NEC data are discussed in Section C.1.1.2 and the relative coverage of these facilities is shown in Figure C.2. For any single aircraft track in the data shown on Figure 5.1, a gap in the data indicates a temporary loss of ARTS coverage at a given facility. The large gaps in data (greater than 16 nm) indicate data from an entire ARTS facility was missing on that specific flight. Table 5.1 may be used to determine which ARTS facility was involved in these data dropouts. For example, on the HH3 Southbound Flight (11-1-78), the Baltimore data was not available. A final and very precise examination of these tracks shows two interesting characteristics of the ARTS III tracking data. First, the distance between indicated aircraft position and desired track always increased as distance from the facility increased. Second, at facility coverage junctures or overlap, discontinuities occasionally occurred. These two ARTS III tracking characteristics will be covered in depth at the end of this section where ARTS III accuracy vs. EAIR accuracy is discussed.

B. STATISTICAL ANALYSIS

In order to substantiate the qualitative interpretation of Loran-C accuracy based on Figure 5.1, statistics were generated as previously discussed. Table 5.2 presents a summary of those statistics to various levels of depth. The first row at the top of Table 5.2 presents an aggregation of all the NEC data collected on both helicopters in both updated and non-updated modes of operation. The net result of all these flights showed that TSCT errors fell within ±0.60 nm of the desired track on a

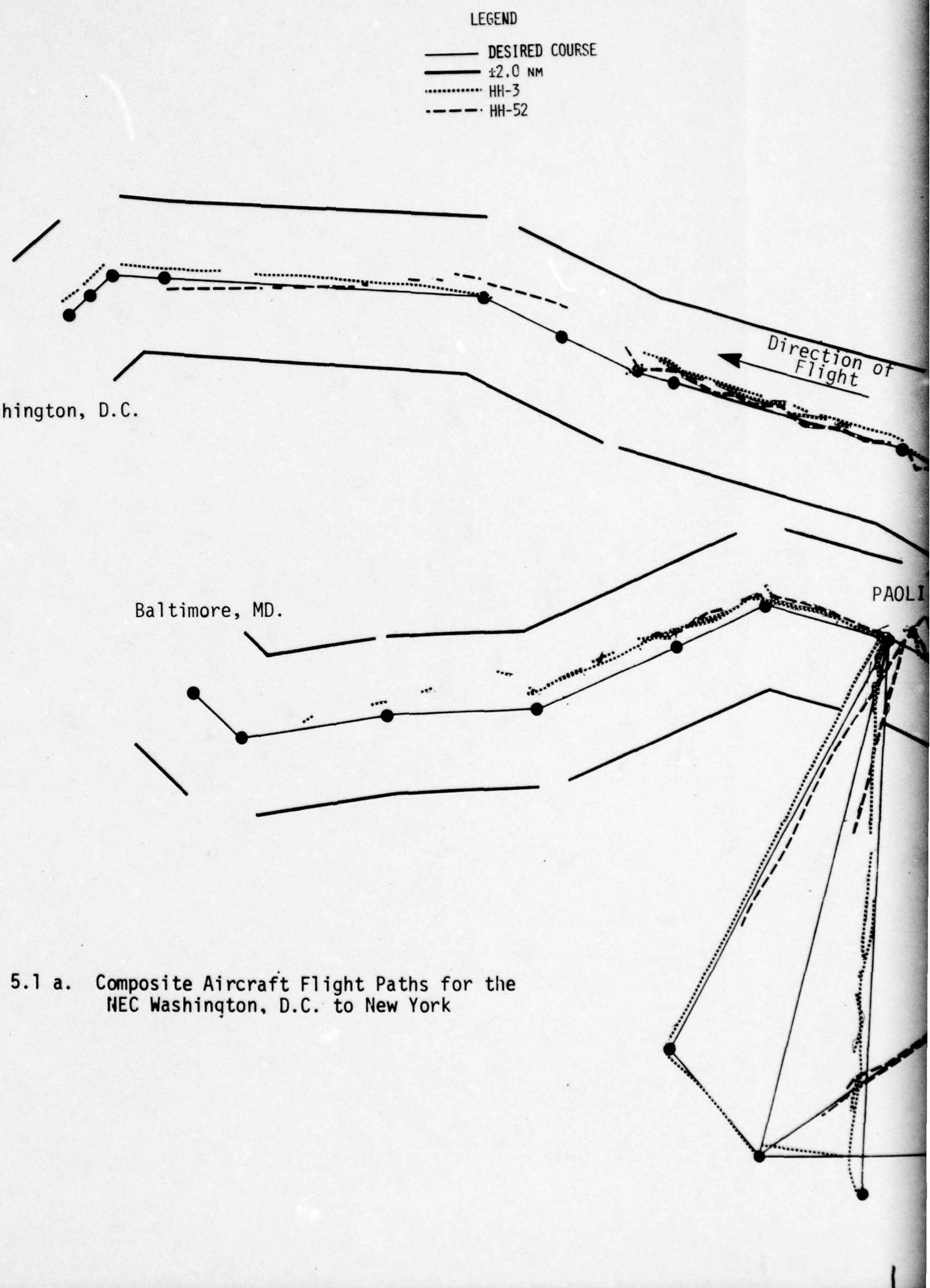
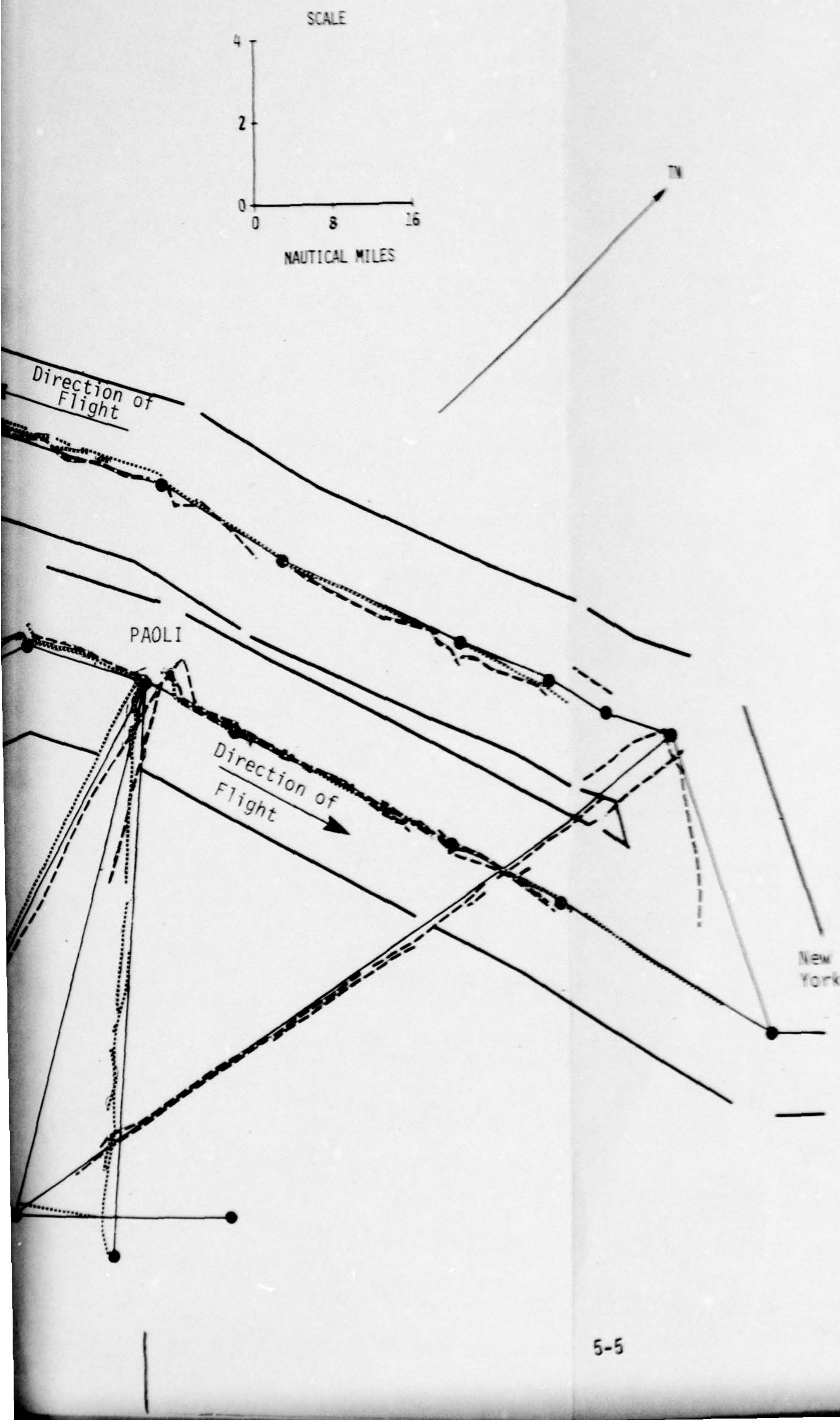


Figure 5.1 a. Composite Aircraft Flight Paths for the NEC Washington, D.C. to New York



SCALE
4
2
0
0
8
16
NAUTICAL MILES
TN
Direction of Flight
PAOLI
Direction of Flight
New York

2

45
46X

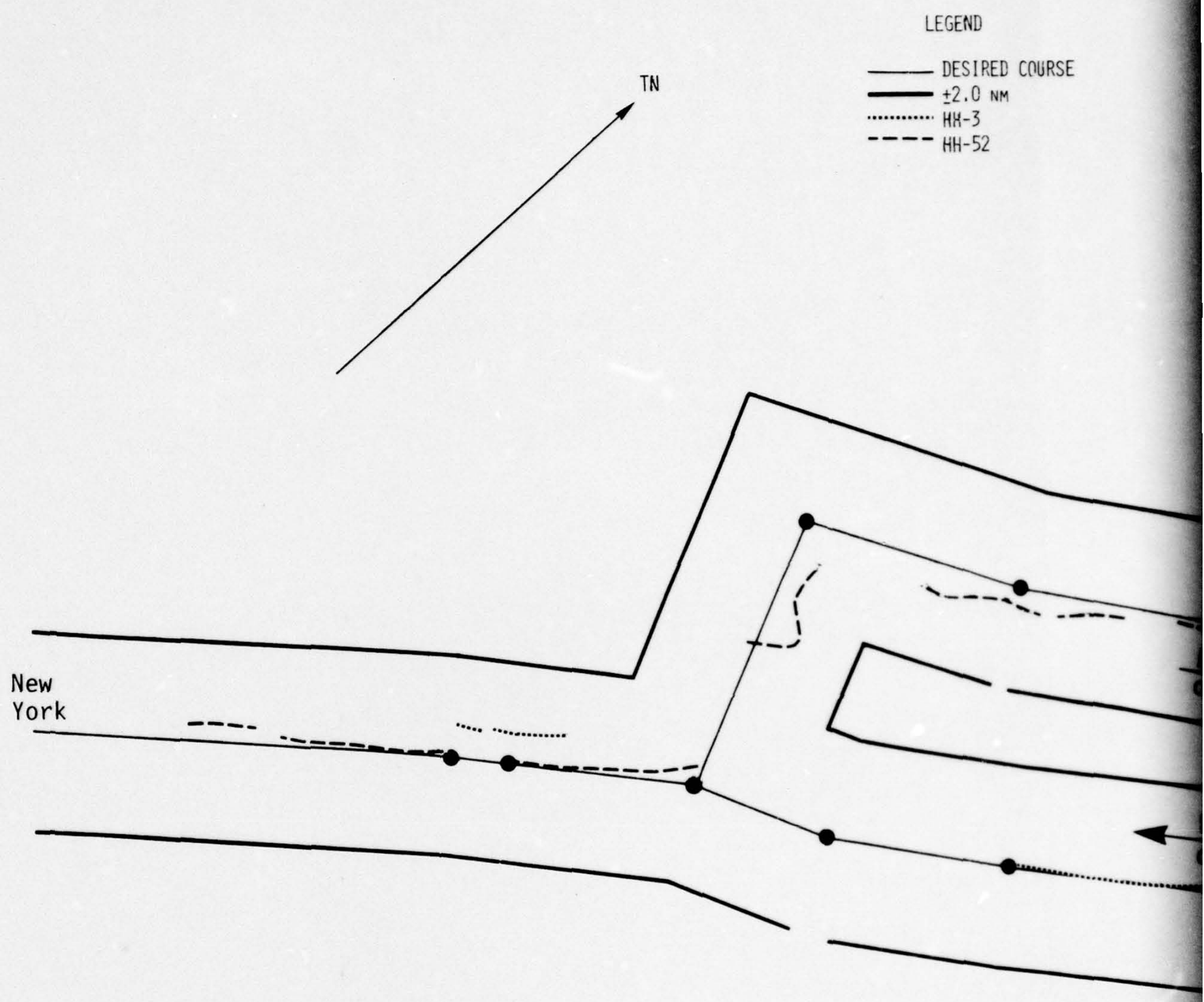
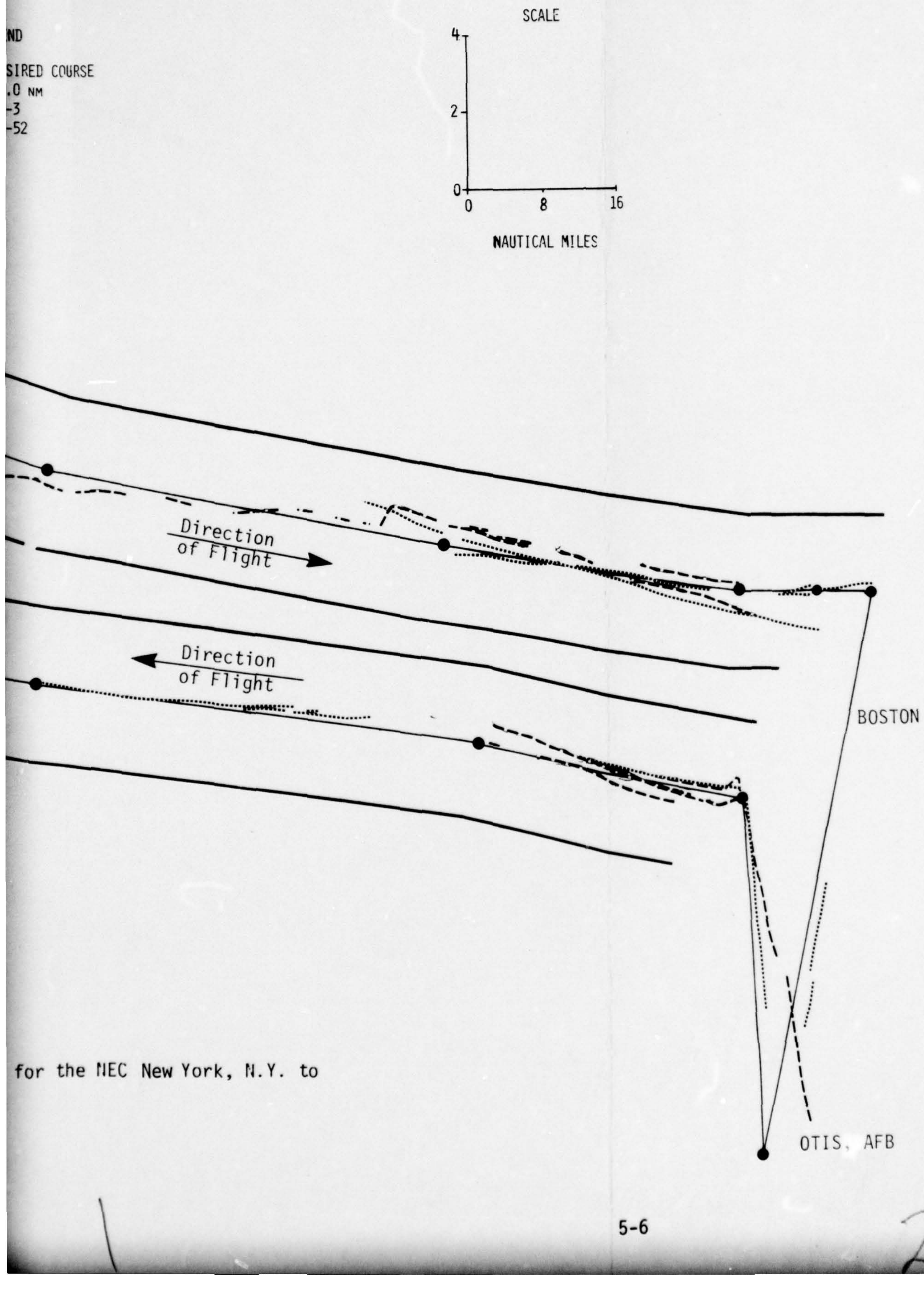


Figure 5.1 b. Composite Aircraft Flight Paths for the NEC New
Boston, Massachusetts



for the NEC New York, N.Y. to

2 47 48X

two-sigma 95% probability basis. The mean error for this data was essentially zero (0.04 nm). The confidence level that ±0.60 nm is precisely correct may be low due to the ARTS tracking accuracy. The implication of this number is that including the inaccuracies of the tracking radar with the Loran-C errors, the data still shows that the aircraft consistently stayed within the ±2.0 nm route width. As was noted on the previous prototype testing, FTE for helicopters using Loran-C is quite small (less than one quarter of a nautical mile two-sigma). This being the case, the remainder of the TSCT error can be attributed to the airborne equipment. For all the data combined the crosstrack component of airborne equipment error (ASE) was 0.58 nm and the alongtrack component (ATE) was 0.69 nm.

Table 5.2 Overall Northeast Corridor Loran-C Data Summary 9960 Chain

Helicopter(s)	Direction of Flight (N=North S=South)	Loran-C Mode (N.U.=Non Updated U=Updated)	TSCT Bias NM	TSCT ±2σ NM	FTE Bias NM	FTE ±2σ NM	ASE Bias NM	ASE ±2σ NM	ATE Bias NM	ATE ±2σ NM	Remarks
HH52 & HH3	N & S	N.U. & U	0.04	0.60	0.01	0.19	0.06	0.58	-0.09	0.69	All Data
HH52 & HH3	N & S	N.U.	0.05	0.61	0.01	0.17	0.07	0.60	-0.19	0.64	Effect of
HH52	N & S	U	0.01	0.58	-0.01	0.21	0.04	0.51	0.11	0.61	Updating
HH52 & HH3	N	N.U.	-0.11	0.39	0.02	0.19	-0.05	0.43	-0.29	0.35	N.U.
	S	N.U.	0.19	0.62	0.01	0.16	0.18	0.64	-0.11	0.77	N vs S
HH52	N	U	-0.06	0.54	0.00	0.30	0.00	0.40	0.39	0.47	U
	S	U	0.05	0.59	-0.01	0.14	0.06	0.56	-0.05	0.43	N vs S
HH52	S	N.U.	0.26	0.78	-0.01	0.14	0.26	0.79	0.16	0.32	Effect
HH3	S	N.U.	0.12	0.34	0.02	0.18	0.10	0.38	-0.37	0.73	of A/C Type
HH52	N	N.U.	-0.15	0.41	-0.00	0.23	0.03	0.48	-0.13	0.22	&
HH3	N	N.U.	-0.08	0.38	0.03	0.15	-0.11	0.36	-0.38	0.27	N vs S
HH52	S	U	0.05	0.59	-0.01	0.14	0.06	0.56	-0.05	0.43	N vs S &
HH52	N	U	-0.06	0.54	0.00	0.30	0.00	0.40	0.39	0.47	Effect of Updating

NOTE: TSCT - Total System Cross Track Error
FTE - Flight Technical Error
ASE - Airborne System Error
ATE - Along Track Error

To combine updated and non-updated data is not rigorously correct even though in an operational sense there may be both updated and non-updated users in the same airspace at the same time. To illustrate the magnitude of updating, the second and fourth rows of data from Table 5.2 should be examined. It should be noted that the real impact of the updated mode on accuracy is not experienced when flying a route which requires more than one secondary pair to be used. This is due to the fact that the AN/ARN-133 correctly zeroes out the first update when changing secondary geometry. In addition, the magnitude of the update accuracy is also masked by any ARTS III tracking errors which may add-to or subtract from the update accuracy depending on route geometry relative to the ARTS facility. With these problems in mind, the update magnitude may still be carefully assessed for qualitative trends as it affects mean TSCT errors. The intended effect of the update is to reduce the bias errors present

for any specified chain geometry. Examination of the combined N and S data in Table 5.2 shows that this did occur. Non-updated TSCT bias was ±0.05 and updated was ±0.01, but this error reduction is much smaller than expected and in fact is probably within measurement tolerances for the data collected. A further analysis of the non-updated vs. updated data for individual N and S tracks (bottom of the table) shows that on the HH52, the non-updated bias was 0.26 and the updated value was 0.05, for a 0.21 nm improvement in accuracy. This is probably a realistic indication of the order of magnitude of the expected effect.

A final examination of Table 5.2 can be made to investigate possible TSCT, FTE or ASE differences due to aircraft size, speed or maneuverability. Comparing the HH3 data (large, 140 knot aircraft) to the HH52 data (small, 80 knot aircraft) revealed no significant observable differences. Detailed segment by segment statistics for both test aircraft are presented in Appendix A. This data should be referred to for a more specific comparison of the two types of aircraft under identical Loran-C geometry conditions.

In summary, an overall assessment of the four performance measures shown in Table 5.2 results in the following set of error magnitudes:

±2σ Error Summary

	Maximum	Minimum	Aggregate
TSCT	0.78 nm	0.34 nm	0.60 nm
FTE	0.30 nm	0.14 nm	0.19 nm
ASE	0.79 nm	0.36 nm	0.58 nm
ATE	0.77 nm	0.22 nm	0.69 nm

This assessment reinforces the observation previously made regarding Loran-C accuracy. Specifically, the overall performance of Loran-C in the NEC for a large number of flights showed that a ±1.0 nm two-sigma value was never exceeded. This certainly substantiates the ability of a Loran-C equipped aircraft to remain within the ±2.0 nm NEC route width. However, this is not meant to imply that there were no significant problems associated with Loran-C navigation in this airspace environment. The following paragraphs present, discuss and analyze the Loran-C utilization from an operational viewpoint.

C. OPERATIONAL ANALYSIS

A total of 58 events indicative of potential operational problems occurred during the Northeast Corridor evaluation of Loran-C. These events were in the areas of Air Traffic Control, Pilot/Copilot procedures and Loran-C navigator hardware/software. This section presents the details of what occurred and the frequency of occurrence. Whenever possible, an attempt has been made to indicate the underlying reasons or causes for specific problems.

Table 5.3 presents a summary of the operational events encountered, the date of occurrence, the direction of flight on the NEC routes and the type of aircraft in use. The 58 events documented in Table 5.3 are categorized into ATC events, Pilot/Copilot events, and Airborne System Difficulties. On a realtive basis, Table 5.3 shows that 27 operational problems were classed as pilot/copilot, 22 as Airborne

Table 5.3 Summary of Operational Events (Relating to Certification)

AN/ARN-133 NEC TESTS

	DATE	AIRCRAFT	DIRECTION	ATC EVENTS
1.	11-1-78	HH3	S	High communications workload at JFK, PHL & DCA due to heavy traffic. Average response took 2-3 minutes
2.	11-2-78	HH3	N	*Same as 11-1 for DCA and PHL*
3.	11-5-78	HH3	S	VHF receiver out in A/C. Transmitted VHF and received UHF. This increased workload and communication time
4.	11-5-78	HH3	S	Traffic Deviation on PAOLI to HOTEL segment necessary to maintain altitude separation from B707
5.	11-5-78	HH3	S	Heavy communications workload with PHL
/NOTE/ 11-9 to 12-5 No significant ATC problems (3 flights)				
6.	12-5-78	HH52	N	Communications workload high due to intermittent aircraft receiver
7.	12-7-78	HH52	S	Heavy communications workload MUSIK to FLOPP
8.	12-19-78	HH52	S	ATC coordination problem between PHL and BAL (No handoff from PHL) Pilot resolved the problem by contacting BAL
*9.	12-19-78	HH52	S	Airspace jurisdiction problem during PISA between BAL Tracon, DCA Tower and DCA approach.
/NOTE/ 12-20-78 to 1-18-79 No significant ATC problems (3 flights)				
				PILOT/COPILOT EVENTS
10.	11-1-78	HH3	S	Secondary change recommended by AN/ARN-133 2 minutes to TOLAN. Upon completing this change the "missed waypoint" alert illuminated. Course recaptured with an abrupt maneuver
*11.	11-1-78	HH3	S	Both Pilot & Copilot became disoriented with respect to actual vs desired track bearing and active waypoint (end of flight fatigue and too many waypoints)
12.	11-2-78	HH3	N	After takeoff the pilot elected to go present position direct to BERNY waypoint. ATC requested track bearing, pilot/copilot confusion resulted in pilot taking over AN/ARN-133 operation for about 30 seconds.
13.	11-2-78	HH3	N	Terminated STAR into NAFEC due to simultaneous loss of communications and mild engine power surges.
14.	11-5-78	HH3	S	Crew missed "Advise" for secondary change for 4 minutes. Advise followed by "WARN". Initially copilot changed secondaries without checking the reason for Advise & Warn. Navigator would not accept bad geometry. Copilot changed back to good geometry. Caused 0.8 nm crosstrack excursion during changeover.
*15.	11-5-78	HH3	S	Pilot became disoriented with respect to the actual aircraft's *along track progress. He thought the* AN/ARN-133 had skipped a waypoint. The pilot turned the aircraft around. Both pilot and copilot became confused with increasing DTW. Finally selected present position direct and reacquired course.

*Discussed in the Text.

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Table 5.3 Summary of Operational Events (Relating to Certification) - Continued

AN/ARN-133 NEC TESTS

	DATE	AIRCRAFT	DIRECTION	AIRBORNE SYSTEM DIFFICULTIES
37.	11-1-78	HH3	S	WARN light for 10 minutes between PISA approach to DCA and Andrews, AFB
38.	11-5-78	HH3	S	ADVISE and WARN lights illuminated at 11 min and 15 min, respectively, after takeoff from Otis, AFB. Secondaries were changed & lights cleared in 20 seconds.
39.	11-5-78	HH3	S	WARN light at 39.3 nm to MOURO indicating "not-in-track" caused by the secondaries in use (Nantucket & Caribou). A secondary change to Nantucket and Carolina Beach extinguished the "WARN". A 0.4 nm crosstrack error occurred when secondaries were changed.
40.	11-5-78	HH3	S	WARN flashed briefly at CLINT waypoint
41.	11-5-78	HH3	S	WARN and ADVISE illuminated after passing FLOPP waypoint "not-in-track" and "float" conditions were the cause. Lasted for 18 seconds.
42.	11-5-78	HH3	S	WARN and ADVISE illuminated after passing ROLER (lasted 2 minutes). Then the AN/ARN-133 display went blank (electrical system shutdown) for 12 seconds. AN/ARN-133 reacquired signals and began operating in about 36 seconds.
43.	11-5-78	HH3	N	WARN illuminated (not-in-track) after takeoff from Andrews, AFB. Duration was nearly 6 minutes so the crew proceeded direct to NAFEC. When WARN extinguished (about 10 nm) copilot sequenced to MOISH to RUSEY segment and regained navigation.
*44.	11-9-78	HH3	N	WARN and ADVISE (not-in-track and float) on JONNS to BANKA segment. This lasted for 1 minute and forty-three seconds.
*45	11-14-78	HH52	N	WARN illuminated (not-in-track) on DROUN to DANEY segment. Changed secondaries SNR's too low, changed chains SNR's still too low Could not regain lock-on for remainder of flight
46.	11-15-78	HH52	S	ADVISE light one minute after takeoff cleared by copilot without investigation.
47.	12-5-78	HH52	N	WARN and ADVISE lights on JONNS to BANKA segment. Lights illuminated 39 seconds followed by a 10 second power interruption. Navigator took 45 seconds to reacquire after powerless.
48.	12-5-78	HH42	N	Automatic leg change did not sequence waypoints after passing ROLER. The indicated DTW and CTD showed the aircraft within the "arrive" circle. Pilot sequenced manually after 1.8 nm.
49.	12-5-78	HH52	N	Automatic leg change did not sequence from IGORR to DROUN. Pilot sequenced manually after 0.5 nm.
50.	12-5-78	HH52	N	When switching secondaries at 29 nm to MEEOW from Nantucket/Carolina Beach to Caribou/Nantucket, the ATE was 0.49 nm and CTD 0.03 nm.
51.	12-6-78	HH52	S	At 33.0 nm to CLINT secondary change resulted in ATE of 0.20 nm and CTD of 0.24 nm.
52.	12-6-78	HH52	S	A 50 second WARN/ADVISE light occurred at 8.6 nm to MUSIK (not-in-track and float)
53.	12-6-78	HH52	S	A 2 minute WARN/ADVISE light occurred at 4.8 nm to MUSIK (not-in-track and float)
54.	12-19-78	HH52	S	Navigator display locked in the waypoint position. Reason undetermined Solved by reinitializing.
55.	1-15-79	HH52	N	An 82 second WARN/ADVISE light occurred at 16 nm to JONNS waypoint (not-in-track and float).
56.	1-15-79	HH52	N	At DANEY waypoint an ADVISE illuminated indicating a secondary change. This results in a CTD shift of 0.25 nm.
*57.	1-15-79	HH52	N	WARN/ADVISE illuminated during PISA on MEEOW to SLOTT segment. Navigator was in float for nearly 3 minutes causing the aircraft to overshoot SLOTT waypoint by 0.5 nm.
58.	1-16-79	HH52	N	ADVISE illuminated on the MOURO to CLINT segment indicating a secondary change.

*Discussed in the Text.

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Table 5.3 Summary of Operational Events (Relating to Certification) - Continued

	DATE	AIRCRAFT	DIRECTION	PILOT/COPILOT EVENTS
16.	11-5-78	HH3	N	Overshot outbound course (MOISH to RUSEY) by 0.42 nm due to Loran-C warn light and associated workload.
17.	11-9-78	HH3	N	Overshot PAOLI waypoint 0.6 nm on transition from NAFEC to NEC. Recaptured course in 55 seconds.
18.	11-9-78	HH3	N	Pilot initiated a 1.7 nm crosstrack course deviation to avoid traffic.
19.	11-9-78	HH3	N	Copilot did not notice "Advise" for three minutes (DROUN to DANEY) then cleared it without checking why it illuminated.
20.	11-14-78	HH52	N	Overshot PAOLI waypoint by 0.78 nm on transition from NAFEC to NEC
21.	11-14-78	HH52	N	Pilot set in an incorrect bearing on CDI due to misunderstanding of copilot instructions.
22.	11-15-78	HH52	S	"Advise" illuminated one minute after takeoff. Copilot cleared it without investigating.
23.	12-5-78	HH52	N	Overshot PAOLI waypoint by 0.6 nm due to strong crosswinds.
24.	12-5-78	HH52	N	Copilot tried interogating AN/ARN-133 for navigation information on PISA. An input error caused loss of Loran-C navigation for 18 sec.
25.	12-5-78	HH52	N	Strong crosswinds on BANKE to ROLER segment caused 0.9 nm cross-track error for 3 minutes.
*26.	12-5-78	HH52	N	Incorrect waypoint L/λ input caused 3035 nm distance error to AVONS waypoint. PISA aborted and reflown after correct input (3 minutes).
*27.	12-6-78	HH52	S	Missed waypoint at ROGEE due to 0.17 nm crosstrack deviation. Manual leg change executed within 10 seconds still 0.37 nm off course. Took 40 seconds to recapture.
28.	12-6-78	HH52	S	Deviated left & right of desired course on MOURO to CLINT while pilot & copilot studied the map. (At 47.6 nm DTW, 40.5 nm DTW and 35 nm DTW) the largest deviation was 0.74 nm.
/NOTE/	12-7 to 12-19-78	No significant pilot/copilot problems (2 flights)		
29.	1-15-79	HH52	N	Pilot inadvertantly replaced active waypoint (BANKA) while trying to input a new waypoint for later in the flight.
30.	1-15-79	HH52	N	Copilot or pilot inadvertantly changed from "auto" to "manual" waypoint sequence while investigating a "warn".
31.	1-16-79	HH52	S	Overshot BANKA waypoint by 1.0 nm. Pilot did not notice auto leg change to TOLAN until full scale fly right indication.
32.	1-16-79	HH52	S	Overshot GRIBL waypoint on GRIBL to BEKEL leg due to missing the AN/ARN-133 "Arrival" circle.
33.	1-16-79	HH52	S	Overshot CLORY waypoint by 1.0 nm. Pilot did not notice auto leg change to TOTAN until full scale CDI deflection.
34.	1-18-79	HH52	N	Overshot MOISH waypoint by 0.5 nm.
35.	1-18-79	HH52	N	Overshot PAOLI waypoint by 0.5 nm. Recapture required approximately 3 minutes due to strong crosswinds.
36.	1-18-79	HH52	N	Incorrect waypoint L/λ input for TULLY waypoint. No significant course deviations. Error caught and corrected by crew.

*Discussed in the Text.

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System Difficulties and nine as ATC related. These events are listed in Table 5.2 chronologically for each category. The summary statement is quite terse and to the point. A more detailed description for each event listed in Table 5.3 is provided in Appendix B.

In order to develop a qualitative interpretation of the character of the three operational event categories, each category was broken down further. ATC events were discovered in four general areas. These were: frequency congestion, airborne radio (transmitter and receiver) problems, route deviations for traffic and ATC coordination. Pilot/Copilot problems were found in seven general categories. These seven categories included: attention/fatigue, Loran-C training, turn overshoots, flight control/navigation, engine problems, route deviations for traffic and waypoint input errors. Finally, the Airborne System difficulties occurred in five areas. These were: warn/advise lights, no automatic leg change, electrical system shutdown, display lock-up and loss of lock on Loran-C ground stations. Table 5.4 presents an analysis and categorization of the 58 operational events experienced during the NEC testing. This table was developed from the list of specific problems listed in Table 5.3.

Table 5.4 Operational Problems in the Northeast Corridor by Type and Frequency of Occurrence

PROBLEM CATEGORY	PROBLEM TYPE	NUMBER OF OCCURRENCES	TOTAL BY CATEGORY
Pilot/Copilot Problems	Turn Overshoots (Pilot)	8	
	Loran-C Training	6	
	Flight Control/ Navigation	5	
	Attention/Fatigue	3	
	Waypoint Input Errors	3	
	Engine Problems	1	
	Route Deviations For Traffic	1	
Pilot/Copilot Total			27
Loran-C Navigator Problems	Warn/Advise Lights	16*	
	No Automatic Leg Change	2	
	Electrical System Shutdown	2	
	Display Lock-up	1	
	Loss of Ground Station Lock	1	
Loran-C Navigator Total			22
ATC Problems	Frequency Congestion	4	
	Airborne Radio (Rec/ Xmit)	2	
	ATC Coordination	2	
	Route Deviation for Traffic	1	
ATC Total			9

*/NOTE/ See Page 5-16 for the Various Causes of Warn Lights.

In the pilot/copilot problem area, the most frequently encountered problems were turn overshoots, Loran-C training and flight control/navigation. The turn overshoots occurred most frequently due to the pilot's inattention to the distance-to-waypoint display on the Loran-C navigator. This occurred most frequently on the long (57 nm) route segment from NAFEC to the NEC. These overshoots were due, therefore, to an insuffficent scan frequency of the Loran-C display rather than high workload. Turn overshoots also occurred due to missing the "arrive" circle which causes the Loran-C navigator to sequence waypoints in the automatic mode due to a cross track deviation greater than the diameter of the "arrive" circle. Finally, turn overshoots occurred due to completely missing the automatic leg change or forgetting to sequence legs in the manual mode. In both of these cases, the CDI typically "pegged" before the pilot noticed the problem. The turn overshoot problems are described explicitly in numbers 16, 17, 20, 31, 32, 33, 34 and 35 of Table 5.3.

Loran-C training problems ranked second in the pilot/copilot category. These problems included missing warn or advise lights, clearing those lights without investigating their cause, and inadvertantly changing modes or active waypoint data while trying to interrogate the Loran-C navigator or input new data. These problems all can be resolved through development and training in specific Loran-C navigator procedures. These problems are explained in items 12, 14, 19, 22, 29, and 30 of Table 5.3.

Flight control and navigation problems ranked third in the list of pilot/copilot procedural errors. These problems included turn overshoots caused by crosswinds which the pilot did not compensate for adequately, cross track deviations approaching one-half a nautical mile which were not apparently caused by an outside influence and such errors as incorrectly setting the CDI. These are normal procedural errors and are not unique to Loran-C navigation. These errors were documented for later comparison with planned FAA testing in the NEC using VOR/DME, Omega and other navigation systems. These problems are documented in items 10, 21, 23, 25, and 27 of Table 5.3.

Attention/fatigue errors and waypoints input errors occurred with the same frequency during the NEC tests. The former included disorientation with respect to actual alongtrack progress (items 11 and 15, Table 5.3) and crosstrack errors occurring while studying the chart (item 28, Table 5.3). The latter included latitude and longitude input errors (items 26 and 36, Table 5.3) and loss of navigation due to improper Loran-C interrogating procedures (item 24, Table 5.3).

Test data was lost only twice due to operational problems caused by other air traffic or engine problems. As explained in item 13 of Table 5.3, a STAR was terminated prematurely due to mild engine power surges and in item 18 the pilot deviated from the desired course due to traffic.

For the second major category of operational events — Airborne System Difficulties — 22 occurrences caused significant workload or navigation errors to warrant investigation. As shown previously in Table 5.4, the most frequent of these navigator events was the illumination of the warn or advise lights. This occurred 16 times during

the NEC tests and five times during the transition or spur route tests. (The latter occurrences will be discussed in Section 5.1.2.) There are four basic causes which produce a warn light. These are: (1) not in track, (2) lat/lon runaway, (3) leg change calculation, and (4) checksum error. Of the sixteen NEC warn lights, seven were caused by the navigator going into "float" or "not-in-track" modes, six were caused by required secondary changes and the causes of the remaining three were undetermined. From an operational viewpoint it was even more significant to note that four of these 16 warn/advise indications occurred during either takeoff (2) or final approach (2). Although no serious operational problems occurred with three of the four, during the point-in-space approach to Boston, the warn/advise illuminated for nearly three minutes and the navigator was in float for this time. This caused the aircraft to overshoot SLOTT waypoint by one-half a nautical mile. This type of occurrence is a serious operational problem in the approach phase of flight and could become an airspace problem in congested areas.

A more detailed listing of the individual warn/advise light occurrences is provided in Table 5.5. This table includes the date and time of each occurrence as well as the duration and the aircraft's latitude/longitude position at the time of the occurrence. All 21 warn/advise occurrences are listed in Table 5.5. In addition, Table 5.6 provides the recommended secondary changes associated with the warn light summary. Once again, Table 5.6 indicates the aircraft position at the time of the recommended secondary change and the stations in use both before and after the change.

The tabular data from Tables 5.5 and 5.6 is shown graphically in Figure 5.2. This illustration shows that discrete warn/advise lights occurred in the NAFEC, Baltimore, and Nantucket areas while repeated warn/advise indications were obtained in and around the New York City Metroplex, and in the Bridgeport, Connecticut area. Figure 5.2 also shows that the frequency of occurrence of secondary changes was concentrated on the baseline from Seneca to Nantucket.

In addition to the many Loran-C warn/advise occurrences, other navigator problems occurred. These other problems were due to the navigator's automatic leg change function not working properly (occurred twice), electrical system shutdowns (which also occurred twice), display lock-up and loss of ground station lock-on (each of which occurred only once). The cause of automatic leg change malfunction was not determined, but it did occur while the DTW and CTD readouts on the Loran-C navigator indicated that the aircraft was within the "arrive" circle (items 48 and 49 in Table 5.3). In one case a 1.8 nm overshoot resulted and in the other a 0.5 nm overshoot resulted. It is operationally important to note that the warn/advise lights which were followed by electrical system shutdown (items 42 and 47 in Table 5.3) did not cause any significant aircraft track deviations. In one case the warn was on for 2 minutes followed by a 12 second loss of electrical power. In the other case a 39 second warn was followed by a 10 second electrical shutdown. In the first case, the navigator reacquired and locked on to the ground station signals in 36 seconds and in the second case 45 seconds were required. This performance was considered acceptable from both airspace utilization and pilot navigation viewpoints.

Table 5.5 AN/ARN-133 Warn Light Summary

9960 Chain

Date	Local Time	Approximate Duration	Lat	Lon	Secondaries In Use	SNR's	Warn Indication		Comments
							Not In Track	Float	
11-1-78	13:24:00	1:00 min	38° 56.0'	77° 00.0'	Nantucket Carolina Bch	78070 900900	✓		
11-1-78	13:26:00	10:00	38° 58.0'	77° 10.0'	Nantucket Carolina Bch	78070 900900	✓		
11-5-78	12:46:52	0:20	41° 22.01'	71° 02.98"	Caribou Nantucket		✓		Due to Poor Secondaries
11-5-78	12:48:32	0:20	41° 22.28'	71° 05.82'	Caribou Nantucket		✓		Due to Poor Secondaries
11-5-78	13:28:04	"Flash"	41° 17.44'	72° 36.14'	Nantucket Carolina Bch				Warn light "Flashed" "Flashed"
11-5-78	13:40:30	0:18	41° 03.50'	73° 06.16'	Nantucket Carolina Bch		✓ ✓	✓	
11-5-78	13:50:35	2:05	40° 48.82'	73° 28.73'	Nantucket Carolina Bch	88880 000000	✓	✓	Display blanked after 10 sec. Possible Electrical Shutdown
11-5-78	16:59:44	5:50	38° 58.32'	76° 34.38'	Nantucket Carolina Bch	78670 601600	✓		
11-9-78	11:55:25	1:43	40° 21.54'	74° 09.53'	Nantucket Carolina Bch	11110 000000	✓	✓	Possible Electrical Shutdown
11-14-78	13:21:00	4:40:40	41° 15.31'	72° 50.01'	Nantucket Carolina Bch	76670 948800	✓		Warn on Remainder of Flight About 45 min.
12-5-78	11:17:00	"Flash"	40° 22.29'	74° 06.72'	Nantucket Carolina Bch				Warn light "Flashed"
12-5-78	11:23:13	1:34	40° 28.05'	73° 56.28'	Nantucket Carolina Bch		✓	✓	Possible Electrical Shutdown
12-6-78	16:45:06	1:50	41° 12.50'	72° 43.40'	Nantucket Carolina Bch	88880 000000	✓	✓	
12-6-78	16:48:00	2:00	41° 10.60'	72° 47.20'	Nantucket Carolina Bch	88880 000000	✓	✓	
12-7-78	15:20:33	0:06	40° 44.70'	73° 58.00'	Nantucket Carolina Bch		✓		Approach to Helipads on E. River N.Y. City
12-7-78	15:21:10	"Flash"	40° 44.57'	73° 57.47'	Nantucket Carolina Bch				Approach To Helipads on E. River N.Y. City
12-7-78	15:21:20	"Flash"	40° 44.33'	73° 57.68'	Nantucket Carolina Bch				Approach to Helipads on E. River N.Y. City
12-7-78	15:29:13	0:26	40° 48.84'	74° 01.96'	Nantucket Carolina Bch	78770 909500	✓		
12-7-78	15:33:20	0:30	40° 48.49'	74° 05.79'	Nantucket Carolina Bch	70770 905800	✓		
1-15-79	13:23:00	2:22	39° 46.19'	74° 53.16'	Nantucket Carolina Bch	77770 959900	✓	✓	SNR's after Warn Light Out
1-15-79	15:29:00	2:55	42° 09.15'	71° 19.08'	Caribou Nantucket	77770 000000	✓		

The third major operational event category was associated with Air Traffic Control. The difficulties occurring in this category were typical of what would have been predicted for the NEC route. The number of ATC related events was less than half of each of the other major categories. The most frequent ATC problem was in the communications area. Frequency congestion was encountered particularly around JFK, PHL and DCA terminal areas (items 1, 2, 5 and 7 in Table 5.3). This frequency congestion was not considered a serious operational problem, but it did cause a higher than normal pilot workload due to the time correlation communication requirements. These time correlation contacts were in addition to the normal ATC/pilot communications workload and due to the traffic in these areas required repeated attempts. The typical ATC response time was 2-3 minutes for each attempt. In addition to the frequency congestion problem, communications workload was increased on two occasions due to airborne radio receiver or transmitter problems. In one case (item 3, Table 5.3) it was necessary to transmit VHF and receive UHF. In the other case the aircraft reception was intermittent (item 6, Table 5.3). Even with this adverse communications workload due to hardware problems and frequency congestion, none of the Loran-C flights exceeded the specified NEC route width.

Table 5.6 Loran-C Recommended Secondary Change Summary

9960 Chain

Date	Local Time	Secondaries In Use	Recommended Change to	Lat	Lon	ATD Shift (nm)	CTD Shift (nm)	NM Traveled Prior To Change
11-1-78	11:58:00	Caribou Nantucket	Nantucket Carolina Bch	42° 04.50'	71° 16.40'	*	*	
11-5-78	12:44:03	Caribou Carolina Bch	Caribou Nantucket	41° 23.58'	70° 52.42'	o.22 East	0.38 South	2.8
11-5-78	12:46:34	Caribou Nantucket	Nantucket Carolina Bch	41° 22.24'	70° 59.99'	0.16 East	0.40 South	4.9
11-9-78	12:55:01	Nantucket Carolina Bch	Caribou Nantucket	41° 44.95'	72° 00.57'	Secondaries were not changed		98.0
11-16-78	12:03:00	Nantucket Carolina Bch	Caribou Nantucket	41° 46.91'	72° 08.97'	0.33 West	0.45 South	10.4
12-5-78	13:39:00	Nantucket Carolina Bch	Caribou Nantucket	41° 47.92'	71° 54.94'	0.49 Northeast	0.03 Northwest	3.8
12-6-78	12:44:00	Caribou Nantucket	Nantucket Carolina Bch	41° 49.00'	72° 35.52'	Occurred during App.		
12-6-78	14:41:02	Nantucket Carolina Bch	Caribou Nantucket	41° 46.69'	72° 05.96'	0.11 West	0.48 South	
12-6-78	15:01:20	Caribou Nantucket	Nantucket Carolina Bch	41° 40.05'	71° 58.37'	*	*	
12-6-78	15:49:23	Nantucket Carolina Bch	Caribou Nantucket	41° 46.30'	72° 10.03'	0.10 West	0.45 South	0.5
12-6-78	16:12:00	Caribou Nantucket	Nantucket Carolina Bch	41° 38.24'	72° 00.05'	0.20 Northeast	0.23 Northwest	1.5
1-15-78	15:08:00	Nantucket Carolina Bch	Caribou Nantucket	41° 48.30'	71° 54.30'	*	0.25 Northwest	
1-16-79	11:37:45	Caribou Nantucket	Nantucket Carolina Bch	41° 27.22'	72° 20.25'	*	*	

* No airborne data available to quantify the magnitude of shift in navigating from one secondary pair to another

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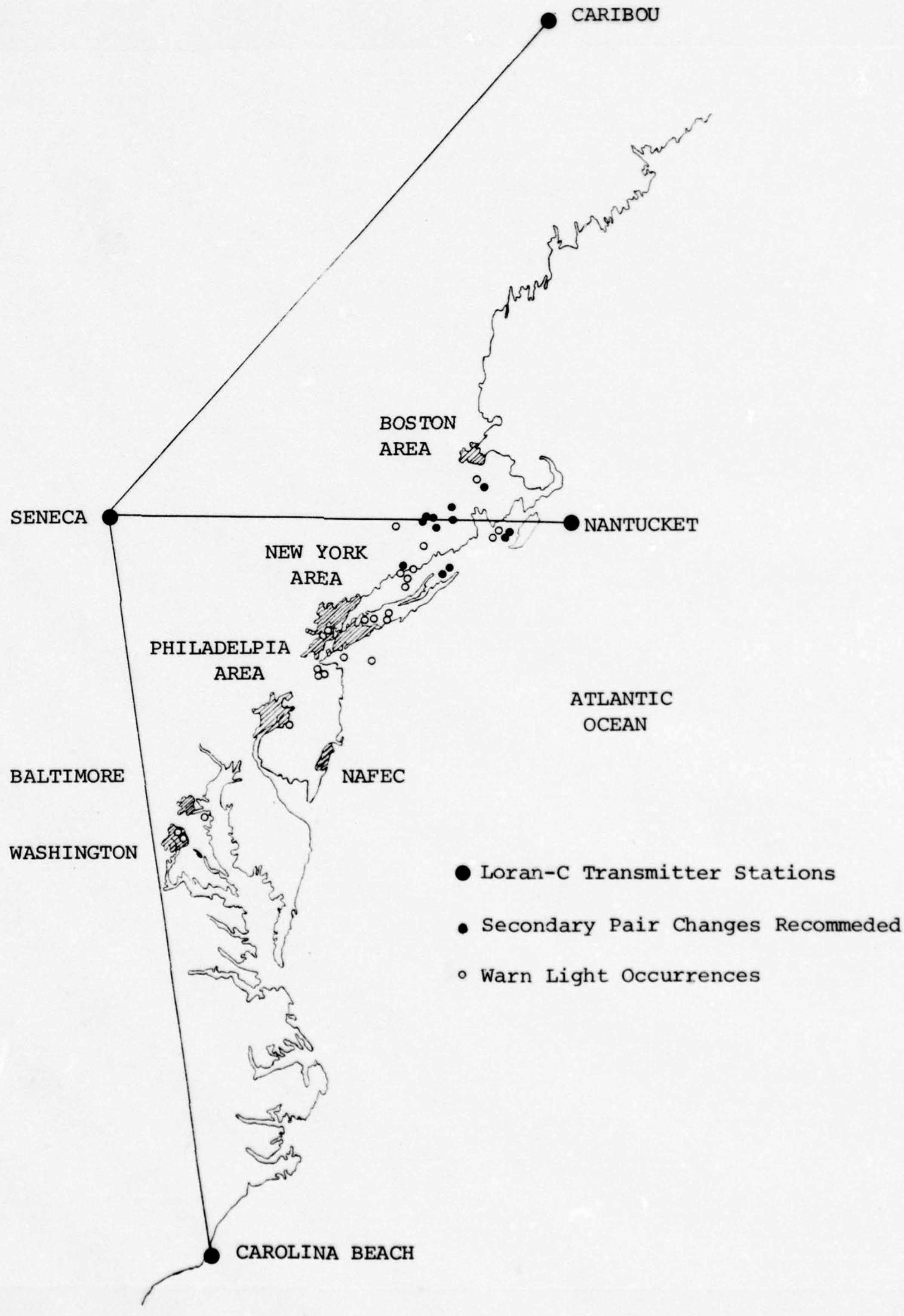

Figure 5.2 Locations of Warn Lights and Secondary Changes During the AN/ARN-133 NEC Testing

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The only two ATC events of operational significance occurred in the area of coordination. In one case, the USCG helicopter was not handed off to the next TRACON and the controllers there were surprised when contacted by the pilot. In the other case, the location of the point-in-space approach to Washington National Airport caused an apparent airspace jurisdictional problem. The first time the USCG HH52 attempted the approach, Baltimore TRACON handed it off to National Tower who said the aircraft was outside their jurisdiction. The tower controller then handed the HH52 off to National Approach Control who in turn said that the pilot should contact Baltimore. The situation was eventually resolved and a satisfactory approach was conducted. However, similar ATC jurisdictional questions could arise due to the atypical geometry of the point-in-space approach concept. This type of question is usually resolved through letters of agreement establishing each TRACON's area of responsibility. Due to the relatively new PISA concept, such letters have not been fully coordinated in the NEC to date.

The final ATC related event was a straightforward vector given by ATC to the HH3 in order to maintain proper aircraft separation. This was not an operational problem from an aircraft maneuverability or pilot procedures viewpoint but it did cause a significant deviation from the desired track and subsequent data loss. This occurrance was probably due to the position of the PAOLI waypoint in relation to PHL's approach and departure path when PAOLI is used as a transition waypoint to NAFEC.

The summary, in the area of Northeast Corridor operational events three categories were identified: pilot/copilot procedures; Airborne System hardware/software and ATC events. In these three areas there were a total of 58 problematical occurrences. Of these 58, 27 were pilot related, 22 were navigator related and nine were ATC related. The total number of 58 does not indicate relative significance. For this reason, each of the primary categories were subdivided and errors were categorized and discussed within each category. In the pilot/copilot problem areas, turn overshoots, Loran-C training and flight control/navigation were the most frequently occurring problems. In the Airborne System problem area, the number and variety of warn/advise lights was by far the largest operational difficulty. As far as ATC operations were concerned, only two controller related problems — one jurisdictional question and one hand-off question — were encountered. Both of these were closely related to the test data collection effort rather than being related to "typical" ATC operations.

D. ARTS ACCURACY ANALYSIS

The final item of interest for this discussion of enroute Northeast Corridor test results is an assessment of the tracking accuracy of the ARTS IA and III surveillance radars. In order to collect the data for this effort it was necessary to sample the digital data from the ARTS IA and III radars. This data is not normally used for tracking experiments to obtain data of the precision needed for these tests. Therefore time and tracking statistics from the NAFEC EAIR precision radar were used to determine the ARTS accuracy. Differences were noted between the ARTS data and the precision tracking radar as well as between two different ARTS sites as was expected. These differences were noted between the

different ARTS facilities in the digital data. This should not be construed to mean the controller scope display differences would affect the control of traffic between ARTS centers.

The order to otain the data necessary for this analysis, the USCG helicopter was flown on a route from NEFEC (SIERRA) to TOLAN waypoint on the NEC. During this flight the aircraft was tracked simultaneously by the EAIR precision tracking radar at NAFEC and the ARTS III surveillance radar at Philadelphia. For a small portion of this route segment, the aircraft was also tracked by the ARTS IA at Newark. A schematic of the route flown is shown in Figure 5.3. The flight of interest was flown on December 19, 1978 using the 9960 chain. The aggregate error statistics for this route segment are shown in Table 5.7 for each of the tracking facilities.

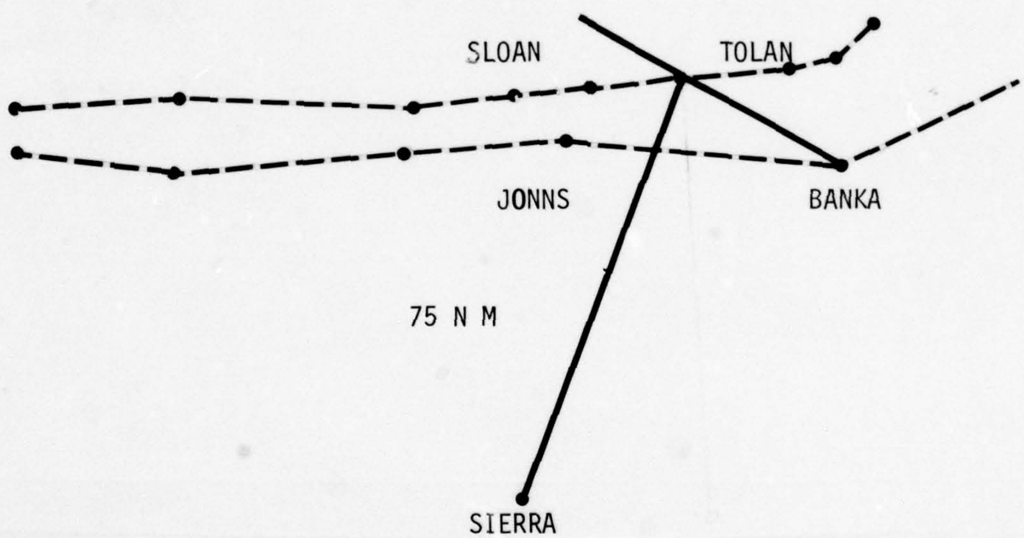

Figure 5.3 Route Segment for ARTS IA and III Accuracy Analysis

Table 5.7 Relative Loran-C Accuracy Using Various Tracking Radars

RADAR FACILITY	TSCT		FTE		NUMBER OF POINTS
	Bias NM	$\pm 2\sigma$ NM	Bias NM	$\pm 2\sigma$ NM	
EAIR	0.09	0.10	-0.03	0.09	674
PHL ARTS III	0.18	0.39	-0.03	0.10	594
EWR ARTS IA	-0.45	0.21	-0.00	0.10	108

(61)

Several interesting facts can be observed in Table 5.7. First, it is important to note that for all three tracking facilities the values of mean and two-sigma FTE are very nearly the same and all are very close to zero. This indicates that the pilot was flying a centered needle and that the variation in his ability to keep the needle centered for this entire segment (roughly 75 nm) was not significant. Second, it is significant that the aggregate statistics are based on a large number of points for all tracking facilities (greater than 100) and in particular that the PHL and EAIR data bases are of comparable size (approximately 600 data points). This being the case, a meaningful comparison can be made to obtain a quantitative assessment of ARTS IA and III tracking accuracy (at least for the two facilities tested).

Examination of the EAIR aggregate data show that on the average the aircraft was within one tenth of a nautical mile (0.09 mean error) for the entire segment. The two sigma deviation about this 0.09 nm mean error was also on the order of one-tenth of a nautical mile (0.10). This 0.10 nm variation can be due to actual aircraft deviations as well as EAIR tracking errors.

In contrast to the EAIR results, the PHL data shows an aggregate average position of nearly two-tenths of a nautical mile (0.18 mean error) and a two-sigma deviation of nearly four tenths of a nautical mile (0.39). If the EAIR position data is taken as the actual aircraft track (mean error) and deviation (two-sigma error), then the PHL results are in error by 0.1 nm and the ARTS III data variability is larger than the EAIR variability by 0.3 nm.

The EWR ARTS IA data is even more interesting due to not only a larger absolute magnitude mean error but a sign change (-0.45 compared to ±0.09). For the sign convention used in the data processing, this means that EWR views the aircraft as being nearly one-half a mile left of course, the PHL ARTS III shows the aircraft nearly 0.2 nm right of course when the actual aircraft position EAIR is only slightly right of the desired track centerline (0.09 nm). These aggregate results were used to show a general trend and an approximate order of magnitude for these ARTS errors. However, in order to critically examine the acceptability of ARTS IA and III tracking it is necessary to analyze the data on a point-by-point basis for the entire track.

Figure 5.4 presents a comparison plot of TSCT, Northing and Easting errors for each of the three tracking facilities. In Figure 5.4, TSCT represents where each facility "thinks" the aircraft actually is relative to the desired track. The Northing and Easting errors are Loran-C errors calculated from measured airborne lat/lon data from the Loran-C navigator. Figure 5.4 shows an even more dramatic difference in all of these errors than would have been expected from the aggregate analysis.

First, Figure 5.4 confirms that the EAIR TSCT mean of 0.1 nm and two sigma of 0.1 nm are approximately correct. Second, the Northing error shown in the figure is initially about -0.1 nm (within ten miles of the EAIR facility) and then begins to increase (approach zero) as distance from the facility increases. The conclusion to be drawn here is that the Northing error is probably -0.1 nm or less with the "or less" being a function or actual error changes over the 75 nm route segment and increasing

(62)

EAIR errors at large distances from the facility. Thirdly, the Easting error in the vicinity of NAFEC is also approximately -0.1 nm but grows to -0.15 nm near TOLAN waypoint (20-10 nm distance in Figure 5.4). Therefore, as best as can be determined, the following are actual observed errors:

$$\begin{aligned} TSCT &= 0.1 \text{ nm} \\ N_\varepsilon &= -0.1 \text{ nm} \\ E_\varepsilon &= -0.1 \text{ nm} \end{aligned}$$

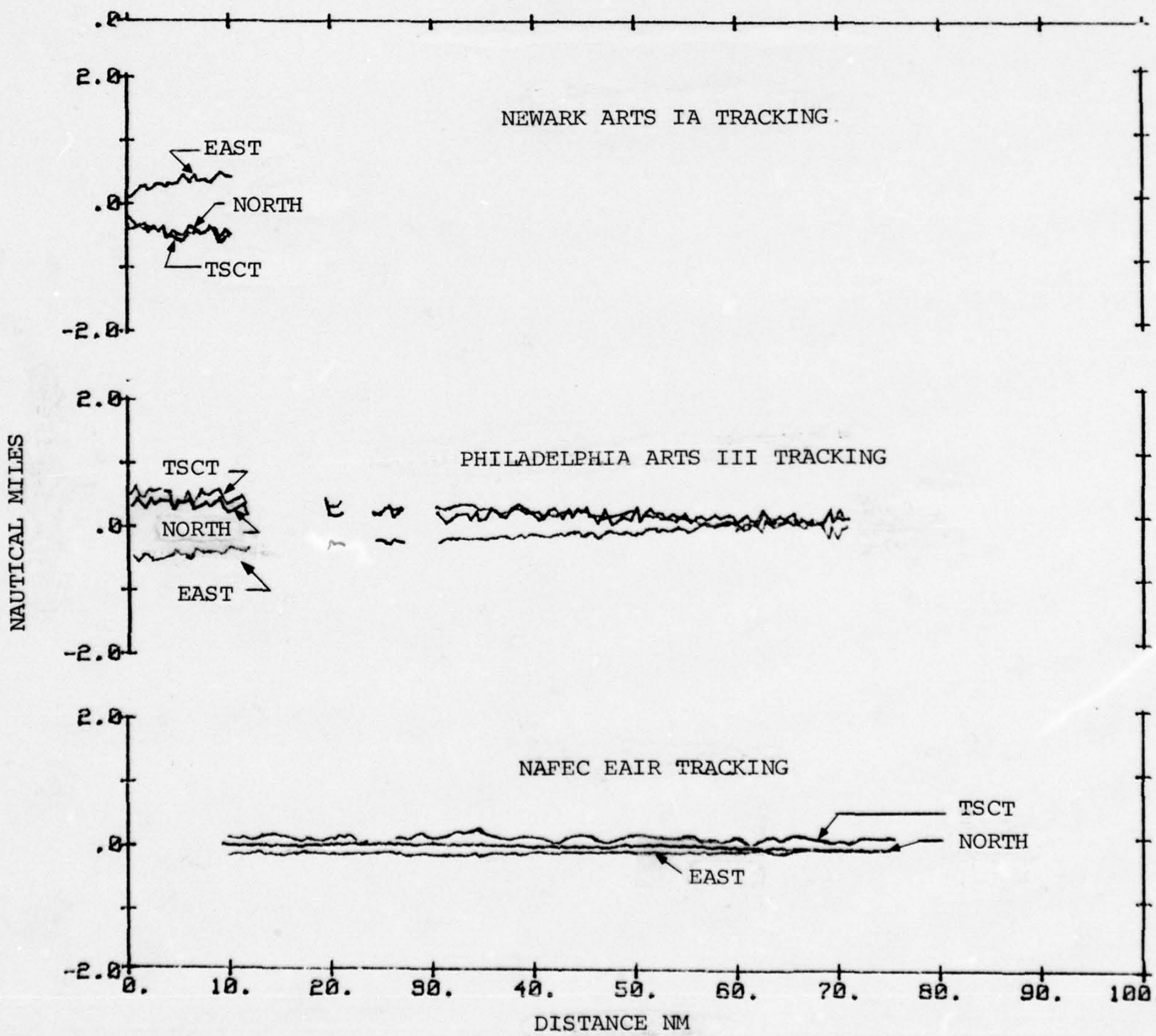

Figure 5.4 Comparison of ARTS IA, III and EAIR Accuracy

As discussed in the analysis of the aggregate statistics, the TSCT error calculated using PHL ARTS III is noisier than the EAIR data. But surprisingly, the PHL TSCT aggregate error is not representative of a PHL aircraft position estimate at any given spot along the route. That is, close to PHL the ARTS III TSCT indicates nearly a zero mean error (70-60 nm distance). The mean error then grows in a linear fashion from zero at the 60 nm point to +0.5 nm at TOLAN waypoint (0.0 nm distance). This large increase in estimated aircraft position is due to the increasing distance from the PHL ARTS III antenna. This growth trend continues until the PHL knowledge of the aircraft position indicates that it is 0.5 nm to the right of course when it is actually only 0.1 nm right.

The Northing and Easting errors calculated during this same time period are based on the Loran-C L/λ data and the TSCT error measurements. Therefore, N_ε and E_ε show growth trends similar to the TSCT data.

Examination of the EWR TSCT, N_ε and E_ε leads to even more inconsistent results. Due to the geometry of the route segment relative to the EWR ARTS IA antenna, and the distance from the antenna, EWR radar data indicates the aircraft is approximately -0.5nm to the left of the desired course (-0.6 to -0.4 nm, noisy data). This data was taken on the fringe of the EWR coverage area and does indicate a decreasing error trend, however, the difference in the actual knowledge of the aircraft's location relative to the desired track is significant where overlapping PHL and EWR data exists. This type of data could present aircraft spacing and separation problems in the handoff airspace between at least these two TRACONs and any others with similar error characteristics. Apparently, these errors are accommodated today through experience and operational procedures without causing any significant operational problems.

To summarize, the detailed analysis of point-by-point tracking data presented in Figure 5.4 has shown that large errors in ARTS IA and III tracking occur at large distances from the antenna (approximately 50 nm). Table 5.8 presents an overall assessment of these ARTS error magnitudes.

Table 5.8 ARTS IA and III Tracking Error Magnitudes

TRACKING FACILITY	INDICATED AIRCRAFT POSITION	ARTS ERROR ESTIMATE
EAIR Indicated Position	0.1 nm	Not Applicable
PHL ARTS III Indicated Position		
<10 nm from the antenna	0.0 nm	0.1 nm
20-30 nm from the antenna	0.0 nm - 0.2 nm	0.1-0.2 nm
40-50 nm from the antenna	Insufficient Data	Insufficient Data
>50 nm from the antenna	0.4 nm 0 0.5 nm	0.3-0.4 nm
EWR ARTS IA Indicated Position		
>50 nm from the antenna	-0.45 nm to -0.55 nm	0.55 nm to 0.65 nm

This table substantiates the qualitative assumption previously stated at the beginning of Section 5.1.1 that a high degree of confidence is not possible when using aggregated ARTS IA and III statistical data. However, this analysis also illustrates that the magnitude of TSCT errors calculated using ARTS data is conservative due to these known ARTS IA and III errors.

5.1.2 Transition (Spur) Routes

In addition to the enroute Northeast Corridor testing previously discussed, several flights were flown on routes which are currently in use, transitioning to and from the corridor. The specific routes tested were representative of operational routes used by Sikorsky Aircraft, Mack Truck, RCA and New York Airways. The data presented in this section assesses the performance of the Loran-C navigator on these routes.

The Sikorsky routes were test flown on 11-16, 12-5, 12-6 and 12-7-78. The Loran-C chain in use was the 9960 configuration. The routes flown were illustrated previously in Appendix B. Reference should be made to the appendix for a picture of the test profiles. Table 5.9 presents the detailed segment by segment statistical data for the Sikorsky Spur routes flown. For each route segment, Table 5.9 lists the "to" waypoint name, the mean and two-sigma error quantities, the tracking facility used and the total number of data points. A thorough scan of this data indicates the maximum TSCT errors occurred on the WINDS to ESSEX and ESSEX to YALES route segments. The value of TSCT mean error for these segments was 0.67 nm. However, this data was on the fringe of the Bradley ARTS III coverage area and may be somewhat conservative. Also the number of data points for these relatively short route segments was small (28). On most other segments with more than 50 data points, the mean TSCT is about one-third to one-quarter of a nautical mile. The major exceptions to this are the DROUN to PRATT segment with 108 data points and a mean error of 0.46 nm and the ROGEE to MOURO segment with a 0.09 nm mean. This data, therefore, indicates that a value of ±0.5 nm mean error is probably typical. However, for worst case airspace planning purposes, values from ±0.7 nm to ±1.0 nm could be used. These values are not significantly different than the overall NEC TSCT results. In fact, these mean errors on a segment-by-segment basis (for a single flight) are adequately reflected in the aggregate enroute two-sigma (95% probability) data. For all of the Sikorsky spurs flown, TSCT mean was 0.06 nm and two-sigma was ±0.69 nm.

Analysis of the enroute FTE data for the Sikorsky Spurs shows that even on short segments with frequent turns, Loran-C FTE in a helicopter is very small due to its high maneuverability and slow cruise speed. The aggregate statistics were 0.05 ±0.21 nm which again substantiated the other NEC results. These enroute aggregate statistics included 1181 total data samples which implies a high confidence level for these accuracy numbers. However, the previously discussed (Section 5.1.1) ARTS III errors also apply to the Sikorsky data. Airborne system error data on the Sikorsky Spurs was not significantly different from any of the NEC enroute data.

As indicated in Table 5.9, nine point-in-space approaches (PISAs) were performed during the Sikorsky tests. These approaches were made

Table 5.9 Data Summary Sikorsky Spur Route Test

HH52 Non-Updated 9960 Chain

WAYPOINT NAME	TSCT Bias	TSCT ±2σ	FTE Bias	FTE ±2σ	ASE Bias	ASE ±2σ	ARTS FACILITY	POINTS
Pratt	.4614	.1524	-.0103	.0648	.4717	.1438	BDL	108
Opler	.2066	.0784	-.0329	.0956	.2395	.0984	BDL	24
Rench	.1095	.1352	-.0011	.0624	.1106	.1436	BDL	47
Rentschler	-.0159	.0850	.0013	.0774	-.0171	.0848	BDL	8
Rocky	-.2960	.1696	-.0100	.1336	-.2860	.0918	BDL	34
Ottis	-.2837	.1892	-.0107	.0542	.2730	.1778	BDL	15
Drown	-.2690	.2226	.0111	.0954	-.2801	.1860	BDL	74
Pratt	.5545	.3780	.0575	.3336	.4970	.1248	BDL	48
Opler	.1960	.1468	-.0158	.0654	.2118	.1330	BDL	24
Rench	.1270	.1514	.0004	.0670	.1267	.1266	BDL	54
Rentschler	.0188	.0994	.0011	.0210	.0177	.0894	BDL	9
Locks	.2066	.2978	-.0107	.1394	.2174	.3102	BDL	81
Daney	-.1745	.2652	.0282	.0752	-.2026	.2914	BDL	38
Opler	.1752	.1026	-.0224	.0804	.1976	.1144	BDL	17
Rench	.1285	.1142	.0096	.0544	.1189	.1094	BDL	48
Rentschler	.0825	.0536	.0700	.0000	.0125	.0536	BDL	3
Meeow	-.1796	.2798	-.0173	.2834	-.1623	.2834	BOS	84
Avows	-.1548	.2346	.1020	.2088	-.2568	.1868	BOS	25
Stacks	-.0449	.1966	.0600	.2468	-.1049	.3630	BOS	13
Dover	-.2174	.7482	.0160	.1406	-.2333	.7678	QUO	89
Rogee	.2811	.3218	.0164	.2984	.2647	.0618	QUO	14
Mouro	.0863	.5746	.0144	.1828	.0719	.5254	QUO	268
Winds	.6692	.1724	-.0189	.1478	.6881	.1018	BDL	28

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Table 5.9 Data Summary Sikorsky Spur Route Test (Continued)

HH52 Non-Updated 9960 Chain

WAYPOINT NAME	TSCT Bias	TSCT ±2σ	FTE Bias	FTE ±2σ	ASE Bias	ASE ±2σ	ARTS FACILITY	POINTS
Essex	.6634	.1330	.0204	.1546	.6430	.0864	BDL	28
Yales	-.1236	.3556	.1310	.3860	-.2546	.0578	BDL	29
Rentschler	-.1876	.1508	.0421	.1702	-.2297	.0452	BDL	28
Locks	.2213	.2092	-.0157	.1178	.2056	.2256	BDL	90
Flopp	-.1543	.2110	.0027	.1628	-.1570	.1110	JFK	108
Clemm	-.1063	.3398	.0024	.1652	-.1087	.2850	JFK	41
Eaton	-.2167	.2908	-.0099	.1856	-.2068	.1744	JFK	69
Coves	-.1944	.2242	-.0065	.1744	-.1879	.1032	JFK	48
Sands	-.1199	.4838	-.0039	.3282	-.1159	.2222	JFK	38
Tower	-.0250	.2470	.0178	.1618	-.0428	.1120	JFK	23
Throg	.1081	.2048	.0128	.1704	.0953	.1904	JFK	29
Point	-.0933	.2684	.0817	.1884	-.1749	.1366	JFK	18
Throg	.2600	.2164	.1220	.1504	.1387	.0902	JFK	10
Track	.3116	.2878	.0617	.2178	.2499	.1166	JFK	41
J.F.K.	.1496	.2244	.0714	.1890	.0781	.1724	JFK	14
Track	.5094	.5576	.5784	.5796	.0690	.1834	JFK	19
Freez	.1276	.3284	-.0137	.2518	.1413	.1428	JFK	79
Jones	.1721	.4600	-.0487	.3670	.2209	.1642	JFK	48
Beach	-.0961	.5928	-.2737	.5862	.1776	.2050	JFK	19
J.F.K.	-.3628	.2298	-.0201	.2070	-.3427	.1536	JFK	87
Aggregation Enroute	.0609	.6853	.0454	.2068	.0607	.6613		1181
PISA	.0133	.4963	.0160	.3221	.0004	.4230		338

during various times of day and with whatever conventional air traffic existed at the time. No special ATC procedures or pre-test arragements were made other than to notify each ARTS III facility prior to take-off that data recording would be required for that day. Under these actual conditions, successful PISAs were executed without any significant pilot or ATC operational problems. The Loran-C accuracy for the PISA data is also shown in Table 5.9. For 838 data points, the mean and two sigma errors measured were:

	Mean	$\pm 2\sigma$
TSCT	0.01 nm	0.50 nm
FTE	0.02 nm	0.32 nm
ASE	0.00 nm	0.42 nm

This navigation accuracy is considered to be quite acceptable for the operational environment tested.

The RCA transition routes to and from the NEC are in the Camden, Deptford, Cherry Hill, New Jersey area. These routes were flown on 11-20-78 using the 9960 chain. Figure B.4 in Appendix B illustrates the route geometry relative to the NEC as well as relative segment lengths and turn angles. Table 5.10 summarizes the data collected on these spurs. The overall qualitative analysis of this data shows that Loran-C performance in this area was slightly better than that experienced further north using the Sikorsky routes. This could be due to either more favorable Loran-C geometry in this geographic location (Sikorsky routes were nearer to Nantucket and some were close to the baseline from Seneca to Nantucket) or due to a higher quality ARTS III tracking. The RCA data was recorded entirely from PHL ARTS III while Sikorsky data was taken from BDL, NAS, BOS and JFK facilities. It is not possible to determine which of those influences resulted in the better performance.

On the RCA spurs, the worst mean TSCT errors were on the order of 0.33 nm compared to 0.67 nm for the Sikorsky routes. The aggregate RCA results are representative of this overall improved performance. TSCT mean and two-sigma results were 0.04 nm ± 0.35 nm for 1007 data points. This data base is of comparable size to the 1181 total points taken on Sikorsky routes. Considering these large sample sizes it is safe to conclude that Loran-C performance was better on the RCA spur routes. The exact amount of this improvement is uncertain due to the different tracking facilities involved and the known ARTS III measurement capabilities.

FTE for the RCA spurs again agreed with the prevous NEC and Sikorsky data. In fact, 1007 data points were taken which produce a two-sigma FTE value of ± 0.19 nm with essentially a zero mean. The large quantity of operational FTE data can be used to validate the NAFEC data base. ASE for the RCA spurs was consistent with the lower TSCT measured.

Data from the Allentown Spur is applicable to users such as Mack Truck who travel from Allentown, Pennsylvania to the Northeast Corridor. The data acquired during these tests was flown on December 8, 9, 1978 using the 9960 chain. PHL and EWR ARTS III data was used to obtain an assessment of Loran-C performance in this geographic area. In addition, the HH52 was

based at NAFEC during these tests and it was therefore possible to obtain EAIR precision tracking for part of this route. Table 5.11 presents all of this data for the Allentown Spur. The top three rows of Table 5.11 have been discussed in detail in Section 5.11 under the ARTS III Accuracy Analysis. At the onset a large TSCT 2σ (.90) and FTE bias and 2σ (-.61 and .68) are observed for the Aware to Sloan segment of Table 5.11. Aware to Sloan is the transition segment from the Allentown Spur to the NEC. During the transition, the aircraft developed a large left Loran-C indicated cross track error of approximately 1.13 nm while executing a right climbing turn from 2700 feet to 4500 feet (based on observer's notes). It is apparent that this maneuver significantly affected TSCT and FTE results.

Table 5.10 Summary of RCA Spur Route Data

9960 Update

WAYPOINT NAME	TSCT M	TSCT ±2σ	FTE M	FTE ±2σ	ASE M	ASE ±2σ	SEGMENT LENGTH	SECONDARIES	ARTS FACILITIES	POINTS
Deptford	.0603	.1032	-.0140	.0606	.0742	.1114	37.2	Nantucket Carolina Bch	PHL	219
Camden	.2466	.1272	.0308	.1416	.2158	.0524	6.0	Nantucket Carolina Bch	PHL	53
Cherry Hill	-.3222	.4056	-.1537	.4270	-.1686	.0732	6.3	Nantucket Carolina Bch	PHL	30
Moorestown	-.0667	.1112	.0015	.0914	-.0682	.0926	5.2	Nantucket Carolina Bch	PHL	46
Jonns	.1520	.1720	-.0007	.0952	.1527	.1636	22.3	Nantucket Carolina Bch	PHL	175
Jonns	-.3118	.0778	-.0090	.0274	-.3208	.0656	8.5	Nantucket Carolina Bch	PHL	10
Moorestown	.1420	.1570	-.0163	.0984	-.1257	.1218	22.3	Nantucket Carolina Bch	PHL	51
Cherry Hill	-.0065	.2962	-.0536	.2408	.0470	.1102	5.25	Nantucket Carolina Bch	PHL	48
Camden	.1369	.0744	-.0333	.0754	.1702	.0586	6.31	Nantucket Carolina Bch	PHL	49
Deptford	-.1397	.3280	.1036	.3676	-.2433	.0704	6.02	Nantucket Carolina Bch	PHL	53
Camden	.2089	.0638	.0912	-.0176	.0668	.2265	6.02	Nantucket Carolina Bch	PHL	29
Cherry Hill	-.2620	.4410	-.1000	.4462	-.1620	.0564	6.31	Nantucket Carolina Bch	PHL	39
Moorestown	-.0580	.1344	.0060	.0776	-.0641	.1164	5.25	Nantucket Carolina Bch	PHL	43
Jonns	.1181	.1972	.0216	.0790	.1595	.1720	22.3	Nantucket Carolina Bch	PHL	156
Hightstown	.2163	.1806	-.0367	.0926	.2530	.2482	2.22	Nantucket Carolina Bch	PHL	6
Aggregate	.0415	.3453	-.0034	.1932	.0532	.2982				1007

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Table 5.11 Summary of Allentown Spur Route Data

WAYPOINT NAME	TSCT		FTE		ASE		ARTS FACILITY	POINTS
	Bias	±2σ	Bias	±2σ	Bias	±2σ		
Tolan	.1780	.3890	-.0334	.0962	.2114	.3382	PHL	594
Tolan	.0883	.1048	-.0287	.0948	.1169	.0430	*EAIR	674
Tolan	-.4548	.2142	-.0010	.0980	-.4537	.1996	EWR	108
Tolan	-.3768	.4758	-.0341	.2390	-.3427	.2936	EWR	104
Spurt	.3581	.2976	.0078	.0866	.3503	.2840	EWR	169
Spurt	-.5334	.1660	.1158	.1110	-.6492	.0914	EWR	12
Aware	.7726	.1906	.0089	.1322	.7637	.1726	EWR	73
Sloan	-.2564	.8978	-.6110	.6764	.3546	.2804	EWR	41
Hayer	.5629	.1682	-.0058	.0618	.5687	.1770	EWR	36
Gribl	-.2779	.1942	-.0062	.1124	-.2717	.1776	PHL	55
Bekel	-.1767	.2230	.0040	.1030	-.1807	.1668	PHL	124
Sinon	-.0922	.2258	-.0249	.2154	-.0673	.0798	PHL	86
Waggs	.0575	.2508	-.0280	.1378	.0855	.2068	PHL	150
Wings	.2160	.2392	.0328	.0984	.1832	.1766	PHL	25
Egner	.4274	.4712	-.0641	.1878	.4915	.3042	PHL	37
Taylo	.5457	.1688	.0278	.0638	.5179	.1514	BAL	46
Rinty	.0583	.5248	-.0050	.1162	.0632	.4988	BAL	143
Clory	-.5074	.0374	-.1600	.0316	-.3474	.0494	BAL	5
Aggregation	.0848	.6956	-.0295	.2430	.1143	.6550		1808

*Error Analysis from EAIR tracking not included in aggregation

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The following discussion will be limited to the analysis of EWR data (Tolan to Hayer), PHL data (Hayer to Egner) and BAL data (Egner to Clory). The overall analysis of this data leaves the impression that the accuracy obtained is more like the Sikorsky data than the RCA data. Yet, the Loran-C geometry is better than for the Sikorsky routes and similar to the RCA routes. Since FTE is again the same as all previous data (0.2-0.25 nm) the pilots actually flew this route in a consistent manner to both RCA and Sikorsky Spurs. Therefore, the only error source remaining is the variation in ARTS tracking facilities used. As previously discussed in Section 5.1.1, the EWR data was significantly different from the PHL and EAIR data which overlapped. This fact shows up in Table 5.11 when comparing Tolan waypoint data for those facilities as well as when comparing data at the Hayer/Gribl transition from EWR to PHL. Once again, the EWR data at Hayer shows a larger TSCT mean error than the PHL data immediately following. Also, as before, the EWR shows the aircraft on the opposite side of the desired track compared to PHL at the transition point. In contrast, the PHL transition to BAL (Enger to Taylo) shows only a slight increase in TSCT mean with the same sign. This data serves to substantiate the trend observed earlier (Section 5.1.1) that the ARTS tracking data is quite sensitive to distance from the antenna and angular orientation relative to the antenna. The analysis of the Allentown spur data is heavily influenced by these observed ARTS errors. A reliable assessment of Loran-C accuracy cannot be obtained for this route. However, it can be concluded that Loran-C performance is no worse than the Sikorsky or RCA data previously discussed. For comparison purposes, the aggregate data showed:

	Mean	$\pm 2\sigma$
TSCT	0.08 nm	0.70 nm
FTE	-0.03 nm	0.23 nm
ASE	0.11 nm	0.66 nm

The New York Airways Spur routes were flown on December 7, 1978, to heliports in the East River and Hudson River areas of New York and New Jersey. The waypoints used in this test were the Pan Am helipad (Pan Am), LGA E. 34th Street helipad (LGA E. 34th), World Trade Center (WTC), Newark Dock or Ramp (EWR Dock) and Teterboro Airport (TEB). As shown in Figure B.5 of Appendix B, Section B.1, the planned route was designed to use prominent visual references as waypoints (Williamsburg Bridge, Manhattan Bridge, Brooklyn Bridge, Governor's Island, and Lincoln Tunnel). However, these waypoints were not programmed into the computer for navigation during the test. The extra waypoints would have increased cockpit stress in programming because of their rapid use (about one every 40 seconds on the East River). Although fewer waypoints were used, the routes flown remained very similar to the planned routes as shown in Figure 5.5. The routes flown utilized those waypoints not programmed, as visual references only. This led to extensive use of the Hudson and East Rivers as desired flight paths since altitude obstructions, TCAs, arrival and departure traffic routes, as well as fuel considerations were hinderances to flying direct routes over Manhattan Island. As a result the routes were considerably simplified. As shown by the composite airborne Loran-C data in Figure 5.5, this test demonstrated the ability of the Loran-C navigator to provide accurate and repeatable navigation to

waypoints in an operational environment which necessitates use of visual references. These visual reference and waypoint defined routes demonstrated minimum air traffic conflicts, normal controller communication workload, and a minimum of navigator programming time. Figure 5.5 shows that the repeatability of the desired routes were acceptable even though visual reference was used to supplement the Loran-C navigation information.

Also shown in Figure 5.5 are segments 1, 2 and 3 which typify the procedures used to navigated waypoint and visual reference defined routes. Segment 1 is a flight from Pan Am to EWR Dock. For this flight only waypoints Pan Am and EWR Dock were programmed into the navigator. The flight began at Pan Am helipad and proceeded visually on the East River southbound. Visual references used in addition to the East River were the Williamsburg Bridge, Manhattan Bridge and Brooklyn Bridge. The aircraft then proceeded between the tip of Manhattan and Governor's Islands and up the Hudson River. The aircraft remained visual on the Hudson River until it intercepted the navigator's course near the Lincoln Tunnel from Pan Am to EWR Dock. From here the aircraft followed Loran-C navigator guidance to EWR Dock.

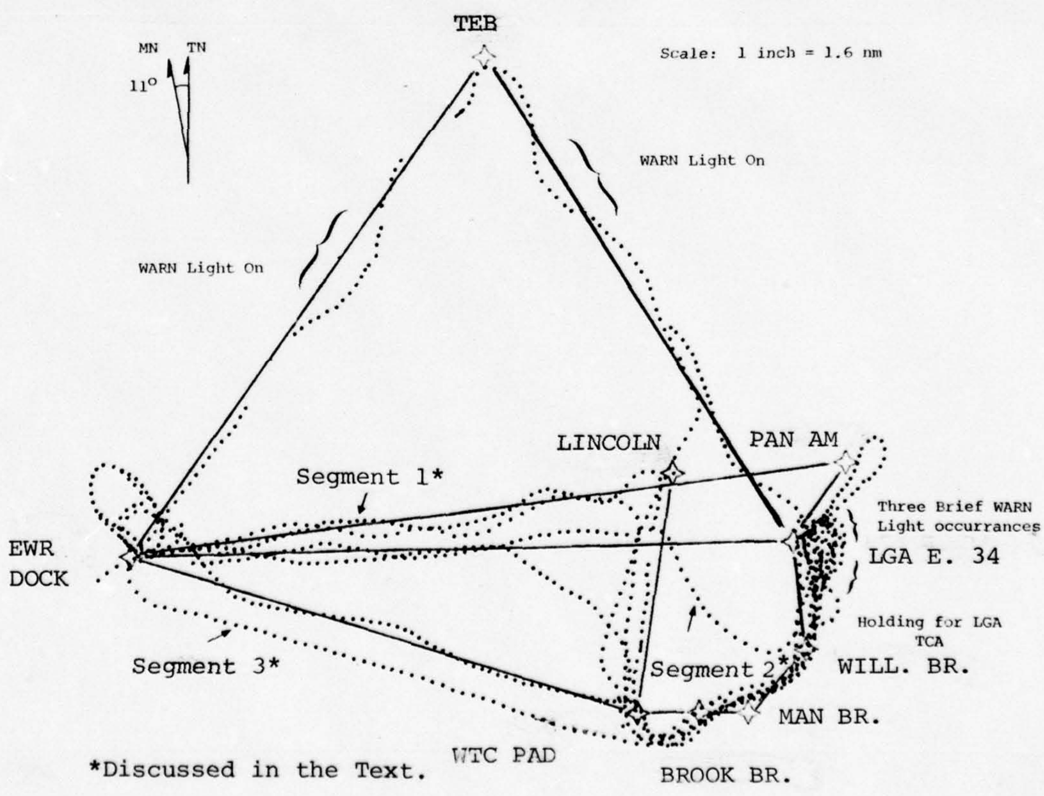

Figure 5.5 Airborne Loran-C Plot of the New York Airways Spur Route Flight Test

Segment 2 (Figure 5.5) illustrates a route from waypoints LGA E. 34th to EWR Dock in which the aircraft circled over the East River to gain altitude, then flew over Manhattan Island to intercept the desired route to EWR Dock. This procedure was not repeated because of conflicts with EWR, LGA or JFK TCA traffic and unnecessary expenditure of fuel. The visual route around Manhattan was preferred to the flight over Manhattan because of the added stress, workload, communications, and fuel required to fly over the island.

Segment 3 defines a route which the aircraft flew from waypoints EWR Dock to LGA E. 34th. In this case the aircraft navigated visually from EWR Dock to a point on the Hudson Bay between Manhattan and Governor's Islands. The aircraft maintained visual navigation up the East River while monitoring the Loran-C navigator's CTD. This procedure made it possible for the aircraft to close-in on the LGA E. 34th waypoint until visual contact with the helipad. Again illustrated by the visual and Loran-C coupled navigation was the minimum workload that the navigator contributed and the repeatability of the navigator to provide accurate navigation.

Depicted in Figure 5.6 is a single flight from Figure 5.5, specifically route segments from EWR Dock to LGA E. 34th to Teterboro each of which defines a waypoint. This figure was plotted from the airborne lat/lon data of the Loran-C navigator. This figure illustrates how the aircraft followed the desired route waypoints (EWR Dock to LGA E. 34th) until it intercepted the Hudson River. The aircraft then flew visually southbound on the Hudson to met the East River, at which point the aircraft proceeded northbound closing in on its cross track error to make an approach to the LGA E. 34th helipad. The aircraft then proceed southbound on the East River to intercept the Hudson River at which point it followed the Hudson until it intercepted the LGA E. 34th to TEB waypoint defined route. The procedure described required less ATC communications than would have been encountered by flying over Manhattan Island on a direct-to route from waypoint LGA E. 34th to Teterboro. Also, as mentioned earlier, a direct-to route from an East River helipad to a waypoint on the opposite side of Manhattan Island requires a circling climb over the East River to about 1500 feet MSL while expending much fuel and placing the aircraft in possible conflict with EWR LGA or JFK departure or arrival traffic.

Another individual flight from Figure 5.5 is shown in Figure 5.7. This route is defined by waypoints from WTC to LGA E. 34th to Pan Am to EWR Dock. This route again used the East and Hudson Rivers as visual reference segments similar to Figure 5.6. This figure portrays the second of two cases of an ATC request to hold during the New York Airways Spur route test (the other hold request, lasting about two minutes, was for traffic and followed an approach to EWR Dock). The request to hold occurred during an approach to LGA E. 34th helipad and lasted for about one minute and 10 seconds. At the time the request was made the aircraft was at an altitude of 800 feet MSL and was encroaching on the LGA TCA. EWR Tower advised the aircraft to hold clear of the TCA. The aircraft executed a missed approach, circled, descended, awaited further instructions for clearance and then completed its approach. This request to hold was not to prevent a specific traffic conflict but was to maintain the aircraft in the proper jurisdictional control space. Executing

the missed approach produced a normal workload procedure. However, within the confines of the East River a hold or a circling missed approach could conflict with the flight paths of other aircraft making approaches to neighboring helipads if proper visual separation is not maintained.

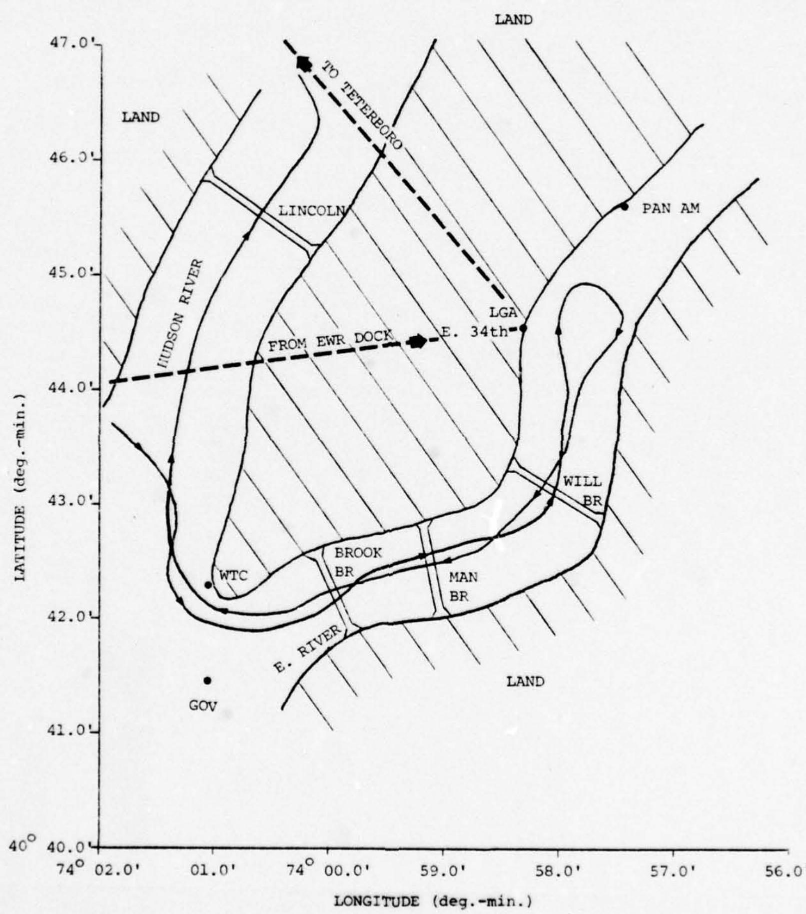

Figure 5.6 Loran-C New York Airways Spur Flight Test (EWR Dock to LGA E. 34th to TEB via East and Hudson Rivers)

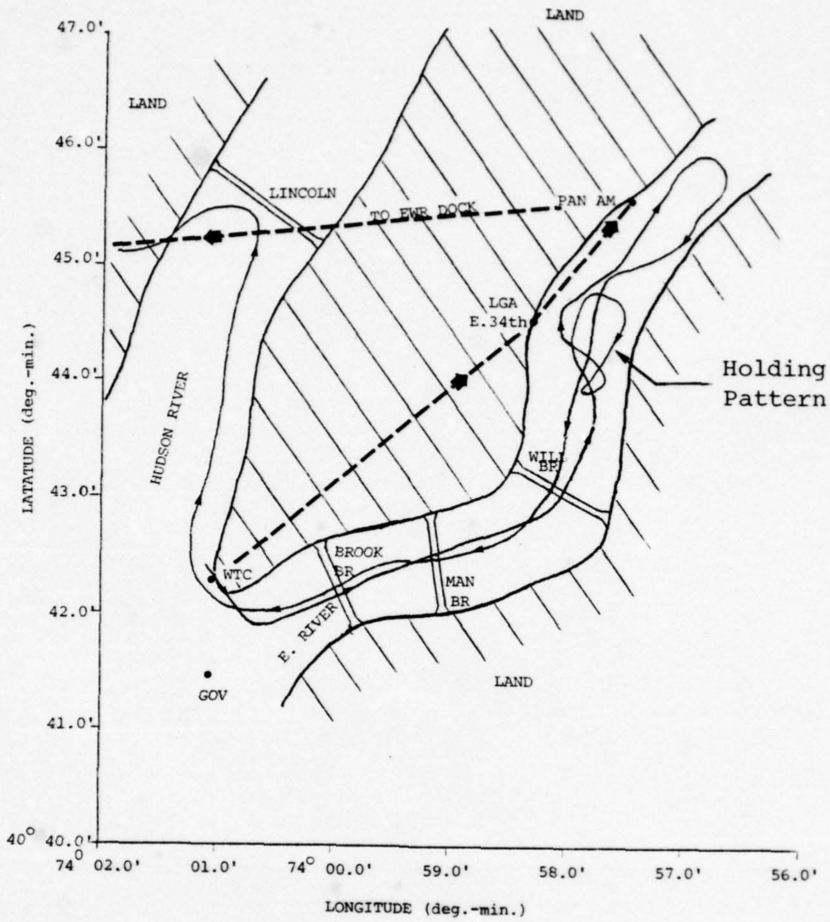

Figure 5.7 Loran-C New York Airways Spur Flight Test (WTC to LGA E. 34th to PAN AM to EWR DOCK via East and Hudson Rivers)

A total of five Warn lights occurred during the New York Airways spur route flight test as shown on Figure 5.5 and summarized in Table 5.12. The first three Warn lights occurred during the approach and departure phase to LGA E. 34th helipad on the East River at altitudes of 100 to 200 feet MSL. The duration was extremely short and did not distrub navigation. It is reasonable to assume, because of the terrain and low altitude, that the loss of signal was due to shielding or grid warpage. The last two Warn lights occurred enroute to and from Teterboro airport at approximately 2700 feet MSL. Of the four reasons for the occurrence of a Warn light, discussed in Section 5.1.1, not in track is the most likely reason for the loss of navigation, indicating a loss of any three Loran-C station signals possibly due to interference.

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Table 5.12 New York Airways AN/ARN-133 Warn Light Summary

Local Time	Approximate Duration	Lat	Lon	Secondaries In Use	SNR's	Warn Indication Not In Track	Warn Indication Float	COMMENTS
15:20:33	0:0:06	40° 44.70'	73° 58.00'	Nantucket Carolina Beach		✓		Approach to Helipads on E. River N.Y. City
15:21:10	"Flash"	40° 44.57'	73° 57.47'	Nantucket Carolina Beach				Approach to Helipads on E. River N.Y. City
15:21:20	"Flash"	40° 44.33'	73° 57.68'	Nantucket Carolina Beach				Approach to Helipads on E. River N.Y. City
15:29:13	0:0:26	40° 48.84'	74° 01.96'	Nantucket Carolina Beach	78770 909500	✓		About 2.4 nm to TEB
15:33:20	0:0:30	40° 48.49'	74° 05.79'	Nantucket Carolina Beach	70770 905800	✓		About 6.0 nm to EWR Dock

5.2 NAFEC SYSTEM ACCURACY TESTING

The data presented in this section can be used to demonstrate the absolute accuracy of the production Loran-C navigator as an area navigation system. This production data base for enroute, terminal and non-precision approach accuracy can be supplemented by the prototype data previously collected and reported in Reference 2. The data presented herein was collected and statistically aggregated using the procedures delineated in Section C.1.2.2. These procedures were designed to be compatible with AC 90-45A compliance procedures and to demonstrate that the tested Loran-C navigator consistently remained within the specified accuracy limits of:

AIRSPACE	TSCT
Enroute	2.5 nm
Terminal	1.5 nm
Approach	0.6 nm

These accuracy limits were superimposed on all subsequent aircraft tracks obtained during the NAS testing of the Loran-C navigator. It should be noted that these limits are more stringent for enroute and terminal airspace than currently imposed by FAA Handbook 7110.18, "Air Traffic Control Service for Area Navigation Equipped Aircraft Operating in the United States National Airspace System". In addition, these requirements are also more stringent than similar requirements placed on VOR/DME referenced area navigation equipment, except for regions in close proximity to the VORTAC station.

Table 5.13 summarizes the overall NAFEC System Accuracy test results for the AN/ARN-133 navigator. The data included in Table 5.13 allows several comparisons to be made. First of all, it is important to note

that all the data in the table was flown using the Non Updated L/λ operating mode, that is, the area navigation waypoint information was pre-specified on the charts shown in Section B.1.2, stored in the Loran-C navigator and flown in a manner compatible with the expected characteristics of an actual NAS user application. With this in mind, Table 5.13 shows a comparison of prototype and production Loran-C navigator data for two different helicopter types and two different Loran-C chains. As was the case for the prototype navigator, the production AN/ARN-133 navigator always remained well within the allotted two-sigma airspace for enroute, terminal and final approach. Aggregate TSCT errors for the navigator never exceeded ±2.0 nm in the terminal area. In the final approach area, TSCT bias errors to runway 04 at NAFEC approached ±0.4 nm, but did not exceed the ±0.6 nm allotted. More final approach accuracy data will be presented and analysed in detail in Section 5.2.3. Table 5.13 does reflect the change of Loran-C chains (geometry). The production HH3 data taken on the new (9960) chain shows a smaller bias error (TSCT) than the corresponding prototype or production data taken with the old (9930) chain.

Flight Technical Error (FTE) data with the production navigator was not substantially different than the prototype unit. The FTE did not seem to increase significantly with the larger and faster HH3 aircraft. Using non-updated (raw) Loran-C signal accuracy did not affect FTE for either the old (9930) or the new (9960) Loran-C chains.

Table 5.13 Summary of Non-Updated NAFEC System Accuracy Test Results

Navigator / Helicopter / Chain	Prototype[1] HH52 9930		Production HH52 9930		Production HH3 9960		AC 90-45A Requirement
Airspace	BIAS NM	±2σ NM	BIAS NM	±2σ NM	BIAS NM	±2σ NM	±2σ NM
Enroute							
TSCT	0.39	0.12	0.42	0.08	.21	.54	2.50
FTE	-0.01	0.09	0.02	0.07	.01	.08	2.00
ASE	0.40	0.09	0.40	0.03	.21	.53	1.50
Terminal							
TSCT	0.03	0.51	0.08	0.46	.13	.32	1.50
FTE	0.01	0.15	0.03	0.10	.02	.12	1.00
ASE	0.02	0.49	0.06	0.46	.11	.32	1.12
Approach (Non-Updated L/λ)							
TSCT	-0.38	0.10	-0.36	0.11	-.26	.08	0.60
FTE	0.02	0.09	0.04	0.12	.05	.09	0.50
ASE	-0.39	0.04	-0.39	0.03	-.31	.03	0.33

[1]Prototype ASE sign convention was changed to satisfy the equation TSCT = FTE + ASE used in the production data reduction.

Examination of the Airborne System Error (ASE) substantiates the results obtained from the TSCT analysis. That is, Loran-C position errors never exceeded ±0.6 nm enroute or terminal and never exceed ±0.4 nm in the non-precision approach data.

Table 5.14 presents production Loran-C navigator test results from NAFEC flown in the updated L/λ navigator mode. These data were collected after an initial position update was input to the navigator while still on the ground. These procedures are similar to the update procedures currently used by air carriers equipped with inertial navigation systems. They initialize the navigation computer by providing information regarding the known starting point, such as a gate location for the air carriers or a helipad for helicopter users. Once again, Table 5.14 shows extremely small TSCT, ASE and FTE error data. Comparison with the allowable AC 90-45A budget value shows that compliance was achieved for this mode in addition to the non-updated mode. The data shown was taken using the production navigator, the old (9930) chain and the HH52 helicopter. No comparable data was taken with either the HH3 or the prototype navigator. A detailed comparison of the data listed in Tables 5.13 and 5.14 shows that for any given airspace, the major effect of the update procedure was to eliminate the larger bias errors measured in the non-updated mode. That was the excepted results, since that is precisely what the update procedure was designed to accomplish. Also, for any particular airspace region, the two-sigma errors (TSCT, FTE or ASE) were slightly reduced.

Table 5.14 Summary of Updated NAFEC System Accuracy Test Results

9930 Chain

AIRSPACE	PRODUCTION NAVIGATOR		AC 90-45A
	BIAS NM	±2σ NM	±2σ NM
Enroute			
TSCT	0.08	0.19	2.50
FTE	0.02	0.12	2.00
ASE	0.06	0.18	1.50
Terminal			
TSCT	0.03	0.24	1.50
FTE	0.01	0.10	1.00
ASE	0.02	0.23	1.12
Approach (L/λ from old TD's)			
TSCT	-0.01	0.11	0.60
FTE	0.01	0.13	0.50
ASE	-0.02	0.05	0.33

5.2.1 Enroute Performance

Figure 5.8 illustrates the results of the enroute flight testing. Two enroute segments were flown as an integral part of the experimental design. The CAPE MAY to VICTOR route segment was 24 nautical miles long and was used to intercept the NAFEC ONE RNAV ARRIVAL (STAR) at VICTOR waypoint. The ROMEO to CAPE MAY enroute segment was 37 nautical miles long and was used to return to CAPE MAY upon departure via the ATLANTIC CITY ONE RNAV DEPARTURE (SID). As can be seen in the figure, all Loran-C flights stayed well within the ±2.5 nm AC 90-45A limits for Total System Cross Track (TSCT) error. In fact, all of the data shown graphically illustrates that the aircraft consistently stayed within ±0.5 miles of the desired track. These flights in general indicated very accurate and repeatable track keeping ability with only a slight bias (about 0.15 nm) to the right or left of track, depending on track heading and direction of flight. The data shown in Figure 5.8 graphically illustrates the removal of the bias error (7-10-78 flight) achieved by using the preflight update procedures. Both HH52 and HH3 aircraft tracks are shown in the figure.

Only one significant track deviation is noted in Figure 5.8. That is, near Romeo waypoint, during the HH52 test on 7-6-78, the aircraft overshot the 115° turn at Romeo by approximately 1.3 nm (see inset B-R-CM). The reason for this turn overshoot is noted on the figure.

5.2.2 Terminal Area Performance

Figures 5.9 and 5.10 present the composite terminal area maneuvering TSCT data obtained during SID and STAR testing, respectively. The airspace limits shown on these figures are ±1.5 nm as specified in AC 90-45A for terminal operations. The summary of flights on each route segment are shown in Table 5.15.

The SID data or Figure 5.9 illustrates even more accurate and repeatable Loran-C performance than was shown for the enroute case. There are four HH52 flights and one HH3 flight on the Bravo to Romeo route segment. These flights all lie nearly on top of each other although the aircraft size, speed and Loran-C chain used were different. The remaining SID segments, Romeo to Sierra and Sierra to Victor, show only two HH52 flights and the single HH3 flight. The reason for this is that the other two HH52 departures flew the route segment from Romeo to Cape May.

Only one significant navigator problem was noted during the SID data collection. The 1.3 nm turn overshoot at Romeo (which was previously discussed in the enroute section) came close to the ±1.5 nm terminal airspace limit. This data provides a cautionary note to Loran-C operators which indicates that while operating in the manual mode the distance to waypoint should be monitored more frequently, especially in terminal maneuvering airspace. Other minor navigator problems are also noted in Figure 5.9. These problems are self-explanatory and did not cause any significant aircraft deviations from desired track.

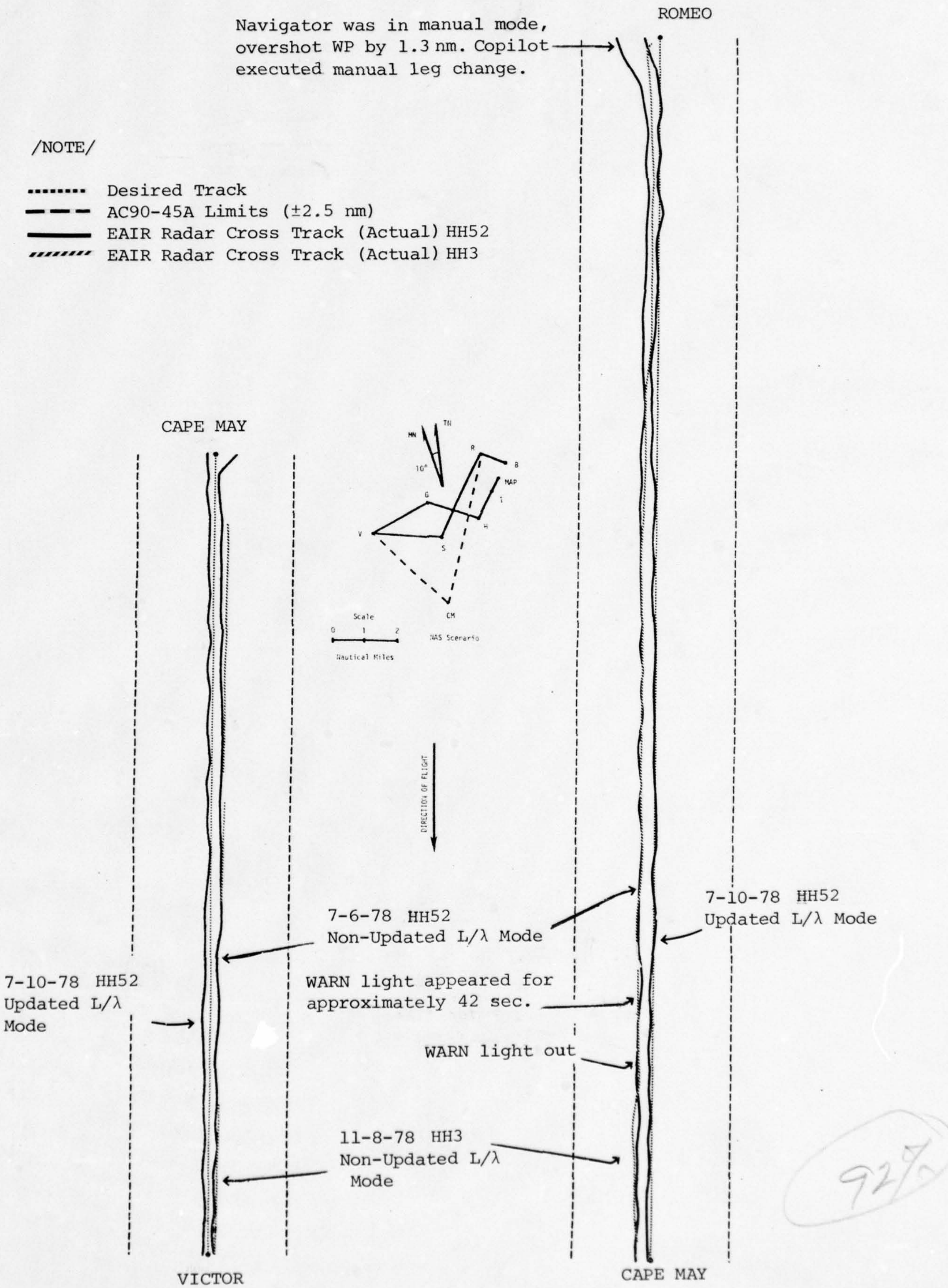

Figure 5.8 Enroute NAFEC Results

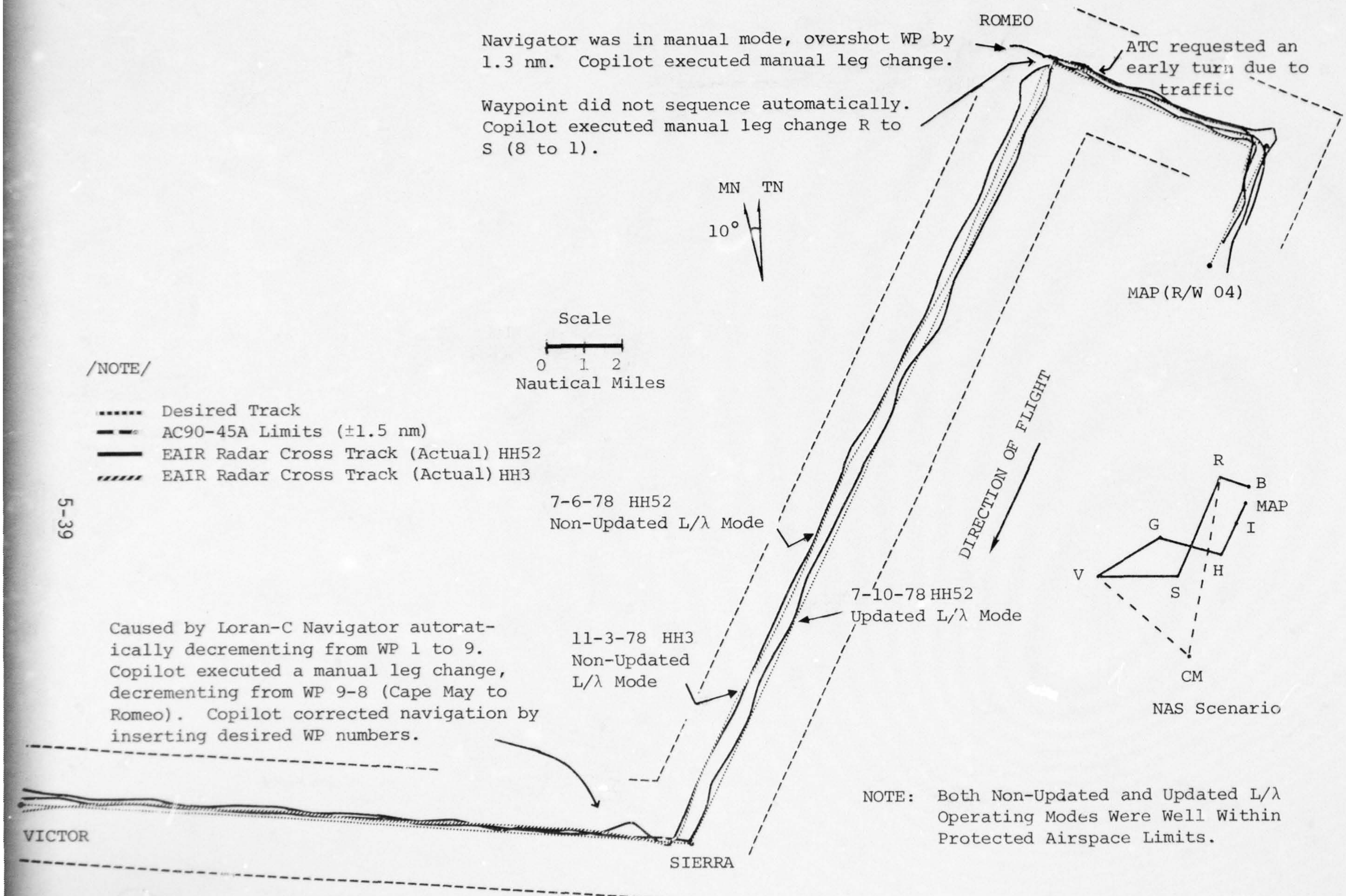

Figure 5.9 SID Data at NAFEC

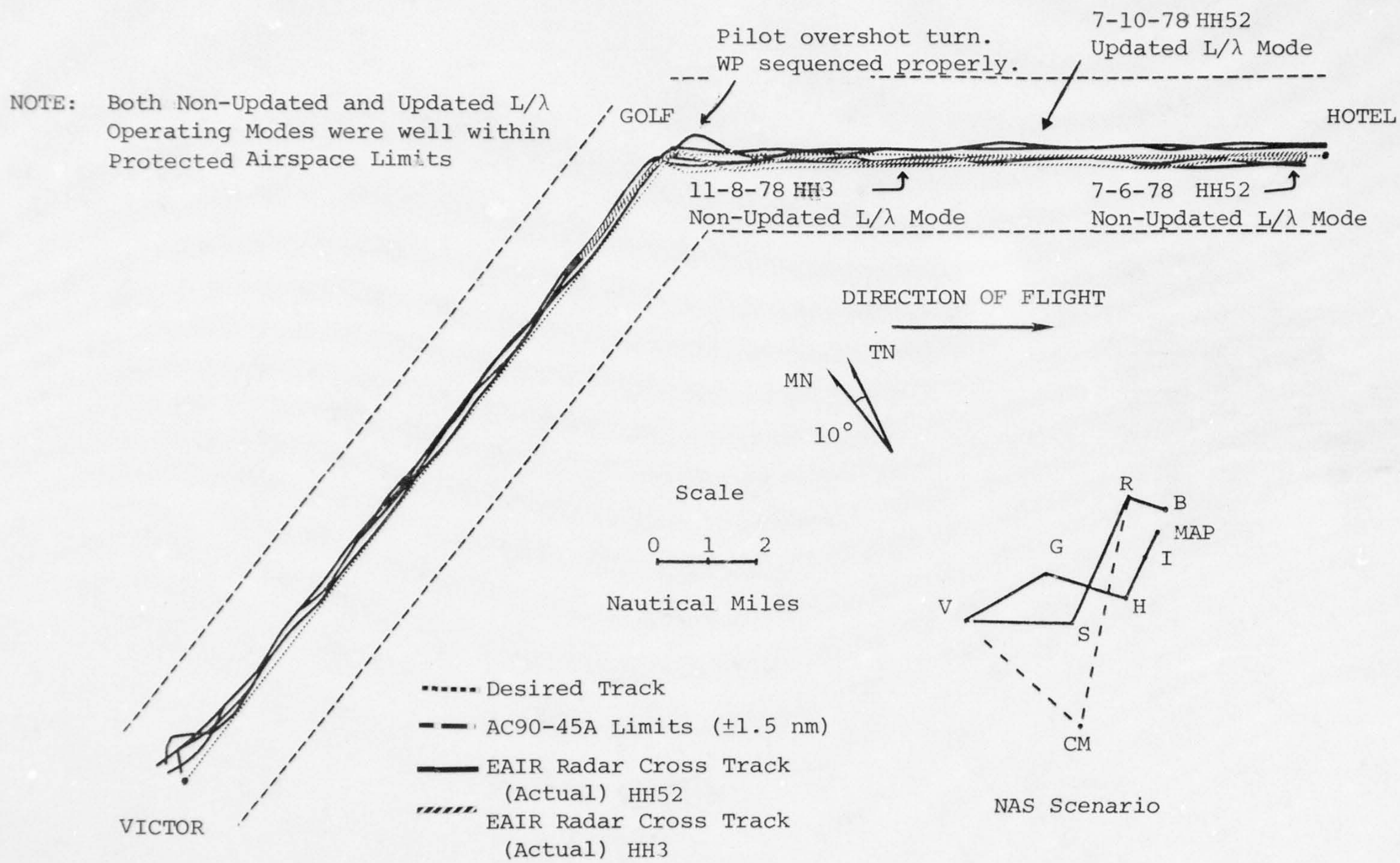

Figure 5.10 STAR Data AT NAFEC

Table 5.15 Terminal Area Data Base on the Production Navigator

Helicopter	Route Segment	Segment Length	Number of Flights
	SID DATA		
HH52	Bravo to Romeo	6 nm	4
	Romeo to Sierra	22 nm	2
	Sierra to Victor	17 nm	2
HH3	Bravo to Romeo	6 nm	1
	Romeo to Sierra	22 nm	1
	Sierra to Victor	17 nm	1
Total SID Segments			11
	STAR DATA		
HH52	Victor to Golf	16 nm	4
	Golf to Hotel	13 nm	4
HH3	Victor to Golf	16 nm	2
	Golf to Hotel	13 nm	2
Total STAR Segments			12
Total Terminal Area Segments			23

One updated Loran-C flight is shown (7-10-78) on the HH52 for comparison with the other non-updated HH52 and HH3 flights. As was previously stated, the updated mode can easily be recognized by the reduced bias error (see Romeo to Sierra segment in particular). It should also be noted that comparing the non-updated HH52 flight (7-6-78) to the non-updated HH3 flight shows the effect of the 9960 chain vs the 9930. Again, on the Romeo to Sierra route segment this caused a more accurate track to be flown.

The STAR data in Figure 5.10 indicates similar accuracy and repeatability to the SID data just discussed. This figure shows four HH52 flights and two HH3 flights. All six flights were within ±0.25 nm of the desired track centerline. None of the STAR data showed any significant operational airspace or navigator problems. Only one slight turn overshoot occurred at Golf waypoint. The magnitude of this overshoot was less than 0.5 nm.

The data shown in Figure 5.10 includes the same 7-6, 7-10 and 11-8-78 HH52 and HH3 flight configurations discussed for the SID results. The particular geometry of the Victor to Golf and Golf to Hotel route segments tested showed no measurable differences for either updated vs non-updated modes or 9960 vs 9930 chains.

5.2.3 Non-Precision Approach Performance

The non-precision approach data presented in this section is that data which was flown as a part of the NAFEC experiment design. This data has been broken out separately to enable a direct comparison between the production navigator and the prototype navigator. Section 5.2.4 will present a much larger final approach data base taken at NAFEC as well as at Frederick, Maryland and Boston, Massachusetts.

Table 5.16 summarizes the particular statistical data base of interest. The data shown can be used to compare different navigator operating modes and two different Loran-C chains, as well as production vs prototype navigator accuracy for non-precision approaches. The data for the HH52 in Table 5.16 illustrates the comparative accuracy of the production AN/ARN-133 navigator tested in July 1978 to the prototype TDL-424 navigator tested in November 1976. Examination of the data where the navigators were flown in the non-updated mode shows outstanding repeatability in TSCT performance (actual aircraft position relative to desired course centerline). The bias error on the prototype (-0.38 nm) and production (-0.36 nm) were nearly identical even though the navigator was tested at two different times of the year. The data from the production unit was compiled from 62 data points while the prototype data consisted of 93 data points. The two-sigma data for these two sets showed ±0.11 nm for the production navigator and ±0.10 nm for the prototype.

Table 5.16 Production Final Approach Data vs Prototype Data for Runway 04 at NAFEC

LORAN-C MODE / AIRCRAFT NAVIGATOR CHAIN	NON-UPDATED L/λ		UPDATED L/λ		L/λ DERIVED FROM MEASURED TD's	
	Bias NM	±2σ NM	Bias NM	±2σ NM	Bias NM	±2σ NM
HH52 Prototype 9930						
TSCT	-0.38	0.10	-0.07	0.06	0.06	0.12
FTE	0.02	0.09	0.00	0.05	-0.01	0.14
ASE	-0.39	0.04	-0.07	0.03	0.07	0.05
HH52 Production 9930						
TSCT	-0.36	0.11	NOT TESTED		-0.01	0.11
FTE	0.04	0.12			0.01	0.12
ASE	-0.39	0.03			-0.02	0.05
HH3 Production 9960						
TSCT	-0.26	0.08	NOT TESTED		-0.28	0.05
FTE	0.05	0.09			0.03	0.06
ASE	-0.31	0.03			-0.32	0.03

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The non-updated HH3 data, using the production navigator, was flown on the new 9960 chain. The TSCT bias error was reduced on the new chain compared to the 9930 data. The 9930/production navigator test data in the HH52 showed a bias of -0.36 nm, while the 9960/ production navigator in the HH3 showed a bias of -0.26 nm (60 data points). The two-sigma TSCT errors were essentially unchanged.

Analysis of FTE for all the non-updated Loran-C final approach data showed that the mean value never exceeded 0.05 nm and the largest two-sigma FTE was ±0.12 nm. Errors of this small magnitude are probably not within the measurement tolerances for the data collection system used. These results simply indicate that FTE is apparently not a problem for Loran-C navigation in a helicopter.

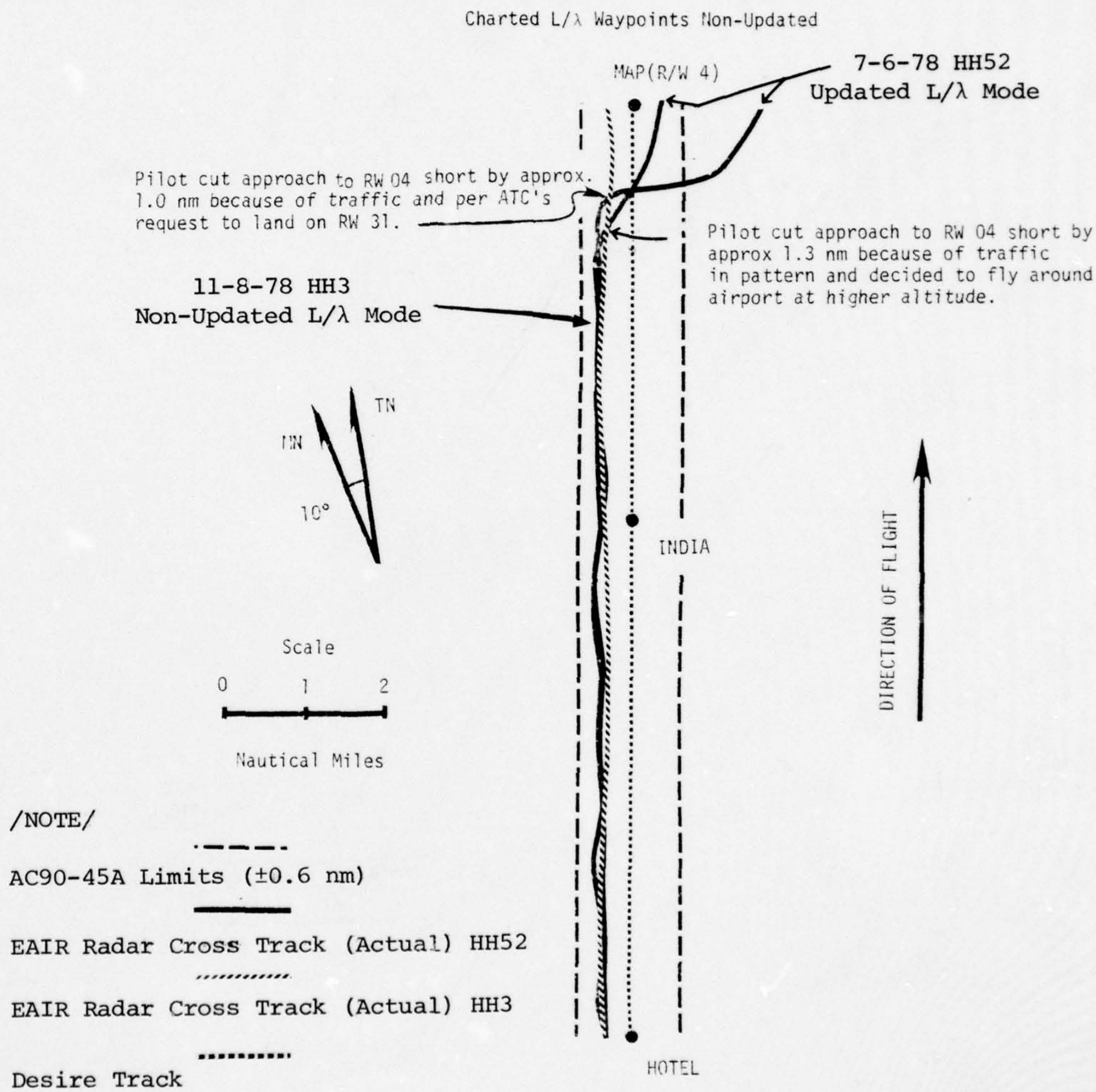
The production navigator was not tested in the updated mode on final approach due to the fact that the behavior of this correction was well defined during the prototype tests and substantiated during enroute, SID and STAR testing of the production navigator.

The final comparison obtainable from Table 5.16 is between the production and prototype navigators operating in the updated mode using calibrated waypoint data. During the prototype tests, the aircraft was hovered over the desired waypoint location as determined by the ground tracking radar. The time differences recorded during the hover (average of twenty points) were converted to lat/lon coordinates by the navigator. These L/λ coordinates were then flown as input waypoint location data in the October 1976 prototype tests and the July 1978 production tests. The data shown in Table 5.16 substantiates that for two different seasons of the year and over long periods of elapsed time (21 months) the Loran-C navigator repeatability was excellent, and the absolute tracking errors were consistently less than ±0.15 nm.

Plots of the final approach data are presented in Figures 5.11 and 5.12. Figure 5.11 shows the actual aircraft tracks overlayed for the non-updated production data on both the HH52 and the HH3 aircraft. For this data, the statistical -0.26 to -0.36 nm bias error is graphically verified by the radar tracks. No significant differences occurred during non-precision approaches to runway 04 at NAFEC in the non-updated mode due either to the differences in helicopter characteristics or the 9960 vs the 9930 chain geometry. Figure 5.12 shows the approach data for the calibrated waypoint location tests. The data shown used waypoints defined by latitudes and longitudes which were based on measured time differences. As previously shown in Table 5.16, this data was accurate and highly repeatable.

5.2.4 AC 90-45A Compliance Data

The acceptable means of compliance for demonstrating Loran-C capabilities as an area navigation system are thoroughly analyzed in Section C.1.2.2. This section will present the detailed and comprehensive data base applicable to satisfying the current AC 90-45A compliance criteria. Due to the complexity of the overall test matrix applicable to compliance and the many independent test variables, this discussion is structured to present a direct "bottom line" comparison of the entire set of measured data to the AC 90-45A criteria. Following



5-11

Figure 5.11 Non-Updated NAFEC Approach Data

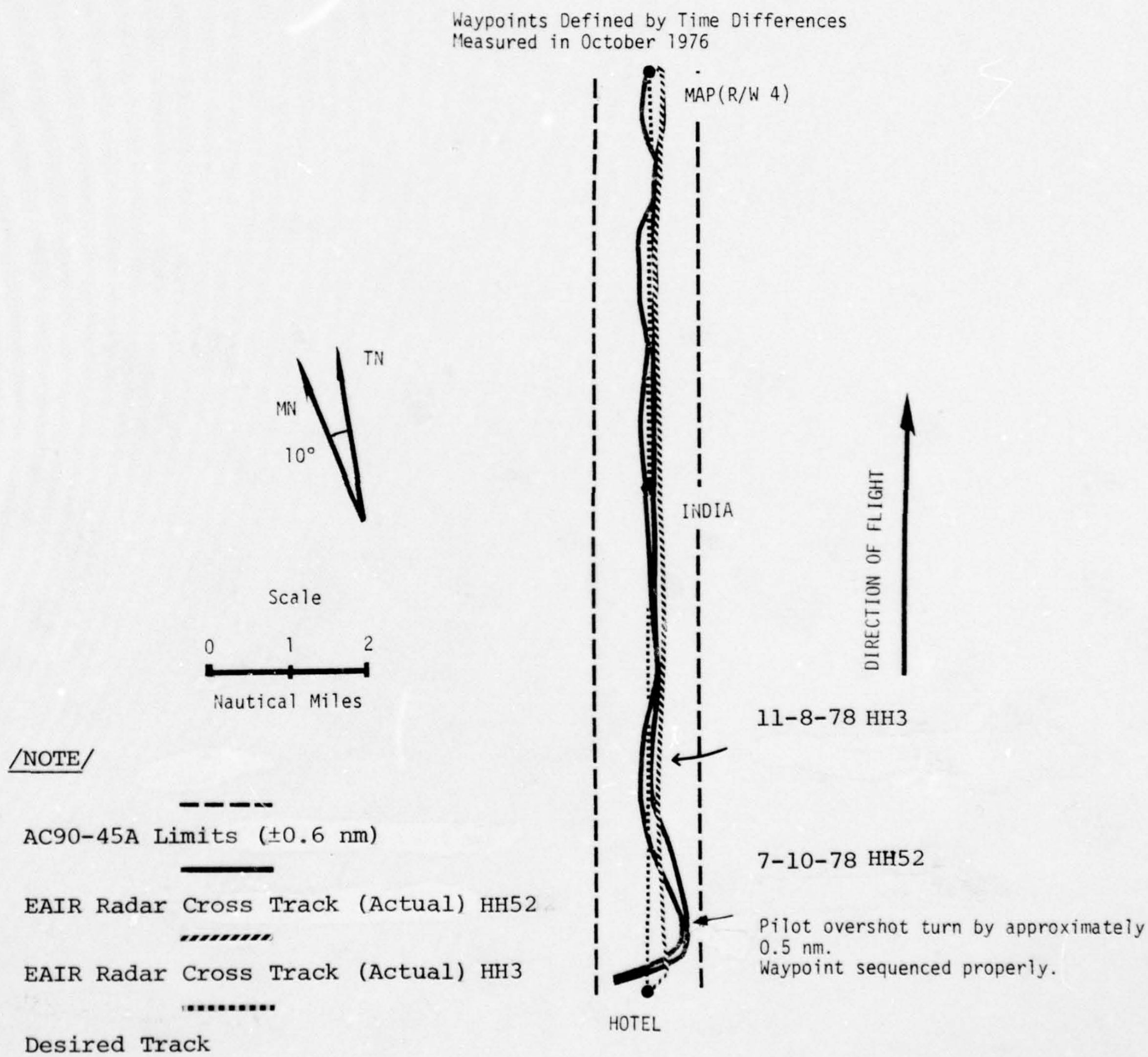


Figure 5.12 Calibrated Waypoint NAFEC Approach Data

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the overview comparison, various levels of more detailed data are presented to enhance the overall understanding of the statistical data base which comprised the "bottom line" numbers.

Table 5.17 compares the crosstrack and alongtrack Loran-C measured data to the specific AC 90-45A requirements. Measured and specified values are shown for enroute, terminal and approach airspace. The measured data shown in Table 5.17 was taken on both the HH3 and HH52 helicopters. The Loran-C navigator was flown in the non-updated mode for this entire data set. The effect of the updated mode has been previously discussed and statistics for that mode will be presented following the compliance discussion.

Examination of the crosstrack values in the table show that for both enroute and terminal operations, the Loran-C consistently performed well within the required limits. Both the AC 90-45A values and the measured values in Table 5.17 are two-sigma, 95 percent probability numbers. The enroute data showed that Loran-C equipped helicopters can fly with total system accuracies improved by as much as 76 percent (the % difference between 2.5 nm and 0.6 nm). Compared to the AC 90-45A requirements the terminal data showed that a 67 percent improvement over the AC 90-45A requirement could be achieved. The lowest relative Loran-C performance improvement was in the final approach area. The comparison to AC 90-45A requirements in this airspace showed only a 17 percent improvement. It can be concluded from these crosstrack statistics that Loran-C performed within the specified crosstrack limits for all three airspace regions.

Table 5.17 Overall Comparison of AN/ARN-133 Accuracy and AC 90-45A Requirements

	Crosstrack		Alongtrack	
	AC 90-45A	Measured	AC 90-45A	Measured
Enroute	2.5 nm	0.6 nm	1.5 nm	0.2 nm
Terminal	1.5 nm	0.5 nm	1.1 nm	0.6 nm
Approach	0.6 nm	0.5 nm	0.3 nm	0.5 nm

In the alongtrack dimension, Loran-C showed similar positive results for enroute and terminal airspace. However, the approach accuracy did not meet the current AC 90-45A requirements. Table 5.17 shows that in the alongtrack direction, Loran-C was better than the required enroute accuracy by 87 percent (1.3 nm) and the required terminal area accuracy by 45 percent (0.5 nm). This performance was once again consistently well within specified alongtrack accuracies and should be considered acceptable. However, on final approach Loran-C did not perform acceptably in the alongtrack error category. Table 5.17 shows that the specified AC 90-45A limit of 0.3 nm was exceeded by 0.2 nm for the statistical data base used. The impact of this degraded alongtrack accuracy during a non-precision approach, would be in properly determining when the aircraft had reached the Initial Approach Fix, the

Final Approach Fix and the Missed Approach Point. Since each of these fixes are normally intercepted during the descent phase of flight, the alongtrack error propagates into an altitude error with respect to specified minimums at each of these fixes. The exact implication of the degraded Loran-C performance in the alongtrack dimension must be determined by the Federal Aviation Administration. However, it appears that at least three alternative interpretations exist. First, Loran-C equipped aircraft could be placarded "not for use during final approach". Second higher minimums could be specified on the approach plates for Loran-C approaches compared to similar VOR/DME approaches. Thirdly, Loran-C could be considered unacceptable for certification. This last alternative seems somewhat severe due to the extremely large navigation accuracy improvements offered in enroute and terminal airspace.

In addition to a direct comparison of measured Total System Crosstrack errors (using tracking radar) to specified AC 90-45A crosstrack error limits, Appendix C, Paragraph 6.b "Error Budgeting" states that--"In establishing an error budget, a system designer may trade off reduction in the errors from one or more sources against increases in the errors from others. Thus, in adding an area navigation computing and display capability to the basic VOR/DME system, it is necessary and possible to compensate for the errors introduced by the new equipment by means of reductions in errors from other sources. Any of the airborne error elements, including Flight Technical Error, may be traded provided the total system accuracy reflected in Appendix D, Tables 2, 3 and 4 are met".

The specific example which follows this paragraph in AC 90-45A is for a VOR/DME system, but it explicitly illustrates the acceptability of reducing the specified FTE value in order to demonstrate compliance. In the case of the Loran-C navigator tested, the measured FTE was consistently much smaller than the values specified in AC 90-45A, Appendix A, Paragraph 2.a (4). Table 5.18 shows this comparison.

Table 5.18 Flight Technical Error Compared to AC 90-45A Requirements

AIRSPACE	CROSSTRACK[1]	
	AC 90-45A	Measured
Enroute	±2.0 nm	±0.11 nm
Terminal	±1.0 nm	±0.13 nm
Approach	±0.5 nm	±0.12 nm

1. No FTE is used in determining alongtrack accuracy

If the measured values of FTE are used along with measured values of airborne system error (ASE) and combined using the root-sum-square (RSS) technique specified in Appendix C of AC 90-45A, the results shown in Table 5.19 are obtained.

This table essentially substantiates the previous data shown in Table 5.17. That is, the calculated and measured enroute accuracies were both ±0.6 nm to the nearest tenth of a nautical mile. Similarly, the terminal calculated and measured values were both ±0.5 nm. In the approach area, the ±0.51 nm calculated served to verify the ±0.5 nm measured with EAIR tracking radar. Therefore, whether calculated or measured, the Loran-C crosstrack performance satisfied each of the AC 90-45A limits.

Table 5.19 Calculated Loran-C Total System Crosstrack Accuracy Based on Measured FTE and ASE

Airspace	Measured Errors		$\sqrt{FTE^2 + ASE^2}$	AC 90-45A
	FTE	ASE		
Enroute	0.11 nm	0.56 nm	0.57 nm	2.5 nm
Terminal	0.13 nm	0.45 nm	0.47 nm	1.5 nm
Approach	0.12 nm	0.49 nm	0.51 nm	0.6 nm

The more detailed statistical results upon which the preceding analysis were based are summarized in Table 5.20 and presented route segment-by-route segment in Appendix D. Table 5.20 can be used to make several interesting comparisons between major test variables. For example, the data taken on the 9930 chain using the HH52 can be used to assess any differences in the production vs the prototype Loran-C navigators. This data shows that for terminal and approach airspace there were no significant differences between the two navigators based on comparisons of TSCT, FTE and ASE. In the enroute case, the production navigator apparently has a larger bias error than the prototype, but this is, in actuality, not true. The production enroute data on 9930 was limited to a single route segment (Romeo to Cape May) with a 195.8° bearing relative to true north while the prototype data was taken on this segment as well as a Cape May to Victor segment (See Figure 5.9 for the relative bearings of these two segments). If the enroute prototype data (mean errors) from Romeo-Cape May are compared directly to that same route segment on the production navigator, the following results are obtained:

	Prototype	Production
TSCT	0.39 nm	0.42 nm
FTE	-0.01 nm	0.02 nm
ASE	0.40 nm	0.40 nm

It can therefore be concluded that no significant differences were measured between the production and prototype navigators. The main reason for showing the more comprehensive prototype enroute data set was to provide a single table where all the data collected could be summarized.

The second comparison shown in Table 5.20 is between the old and new Loran-C East Coast Chains (9930 vs 9960). This comparison is masked somewhat by the fact that the 9930 data was taken with the HH52 while the 9960 data was taken with the HH3. However, Section 5.1 has previously shown that the impact of the two different helicopter types on the error components was not significant. Therefore, by comparing mean TSCT error data from enroute and final approach, it can be seen that the new chain caused a slight decrease in the Loran-C bias error for the chain geometry in the Atlantic City and Cape May, New Jersey areas. This decrease is not observable in FTE due to the extremely small magnitude (0.08 - 0.13 nm) which is more noisy than the other two errors. This bias error decrease will probably be too small to have any significant operational impact.

Table 5.20 Summary of Production and Prototype Loran-C Accuracy Data

Helicopter	Navigator (Mode)	Loran-C Chain	Navigation Errors	Enroute		Terminal		Approach[1]	
				Mean NM	±2σ NM	Mean NM	±2σ NM	Mean NM	±2σ NM
HH52	Prototype	9930	TSCT	0.10	0.56	0.03	0.51	-0.38	0.10
	(Non-Updated)		FTE	0.00	0.12	0.01	0.15	0.02	0.09
			ASE	0.10	0.57	0.02	0.49	-0.39	0.04
			ATE	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
			Total ATD	268	—	362	—	38	—
			No. of Points	812	—	875	—	93	—
HH52	Production	9930	TSCT	0.42[2]	0.08[2]	0.08	0.46	-0.36	0.11
	(Non-Updated)		FTE	0.02	0.07	0.03	0.10	0.04	0.12
			ASE	0.40	0.05	0.06	0.46	-0.39	0.03
			ATE	0.04	0.04	0.02	0.56	-0.17	0.03
			Total ATD	37	—	80	—	11	—
			No. of Points	192	—	515	—	62	—
HH3	Production	9960	TSCT	0.21	0.54	0.13	0.32	-0.26	0.08
	(Non-Updated)		FTE	0.01	0.08	0.02	0.12	0.05	0.09
			ASE	0.21	0.53	0.11	0.32	-0.31	0.03
			ATE	0.10	0.18	-0.12	0.55	-0.18	0.03
			Total ATD	61	—	103	—	11	—
			No. of Points	282	—	438	—	60	—
HH3 & HH52 Production 9960			TSCT	—	—	—	—	0.07	0.41
(Non-Updated)			FTE	—	—	—	—	0.02	0.13
Additional Approach Data			ASE	—	—	—	—	0.03	0.42
Taken To All Runways			ATE	—	—	—	—	0.06	0.53
AT NAFEC			Total ATD	—	—	—	—	48	—
			No. of Points	—	—	—	—	908	—

/NOTES/ 1. Approach data in the first three rows (above the double line) was taken solely to runway 04 at NAFEC.

2. HH52/Production/9930/Enroute data is for a single route segment.

(91)

The third comparison shown in Table 5.20 was that, the Loran-C along-track error bias to runway 04 (ATE = -0.17 or -0.18 nm) did not change significantly for the new chain. The effect of this chain geometry bias error of -0.17 nm when examined for all runway headings at NAFEC is shown in the last set of data (bottom ¼) of Table 5.20. On an aggregate basis, the ATE bias of -0.17 nm for a single runway (04) becomes a $\pm 2\sigma$ value of 0.53 nm for 908 data points a various headings. This effect is discussed more thoroughly in the following paragraphs.

The final item of interest from a compliance viewpoint is a more detailed investigation into the final approach performance of Loran-C. During the prototype testing reported in Reference 2, a characteristic Loran-C bias error was noted (9930 chain was used) as a function of aircraft heading or course bearing. For this reason, specific final approach tests were performed with both the HH3 and the HH52 aircraft. Each aircraft executed several approaches to each runway at NAFEC (04, 22, 08, 26, 13, 31). In this manner, the local behavior of the Loran-C bias error (with the new 9960 chain) can be examined. Figure 5.13 presents the EAIR tracking data for all of these approaches. This data shows the actual aircraft path vs the desired final approach course for each runway. Base leg and final approach TSCT errors were calculated from this data. However, Figure 5.13 shows qualitatively that the Loran-C bias error behaved consistently on reciprocal runway headings for all the data collected. Both HH3 and HH52 data is shown. All flights were flown using the new 9960 East Coast Chain.

Table 5.21 quantifies the TSCT data for each runway heading by aircraft type and for both aircraft aggregated. Detailed statistics for each route segment and for FTE and ASE as well as TSCT are presented in Appendix D. Table 5.21 shows that reciprocal heading runways had mean errors of comparable magnitudes and opposite signs as would be expected (040° = -.31 nm, 220° = +.29 nm). This is true for all runway headings when the sample sizes are comparable. The noted exception is runway 08 where the HH3 mean error data was -0.08 nm and the HH52 mean error data was -0.16 nm. Inspection of Figure 5.13 shows that one of the HH3 flights was more erratic than the others. If this data is edited out, the actual HH3 bias errors to runway 08 more nearly match the HH52 data.

A further analysis of the behavior of this data for both the 9960 and 9930 chains is shown in Figure 5.14. The 9960 data used the master at Seneca and secondaries at Carolina Beach and Nantucket. The 9930 data used Carolina Beach as the master with Nantucket and Dana as secondaries. Considering the vastly different geometries, the similarities in the magnitude and behavior of the bias error are quite interesting. Further analysis of the behavior of Loran-C bias error at this and other geographic locations would be of interest, especially as it affects along-track accuracy. Since the bias error is easily understood and directly related to northing and easting errors at a specific geographic location, it should be easy to identify and quantify throughout a coverage area for given secondary station pair geometry. By reducing the bias error at the signal source or calibrating it out at the receiver, the along track final approach accuracy might be reduced enough to meet the desired AC 90-45A compliance limits.

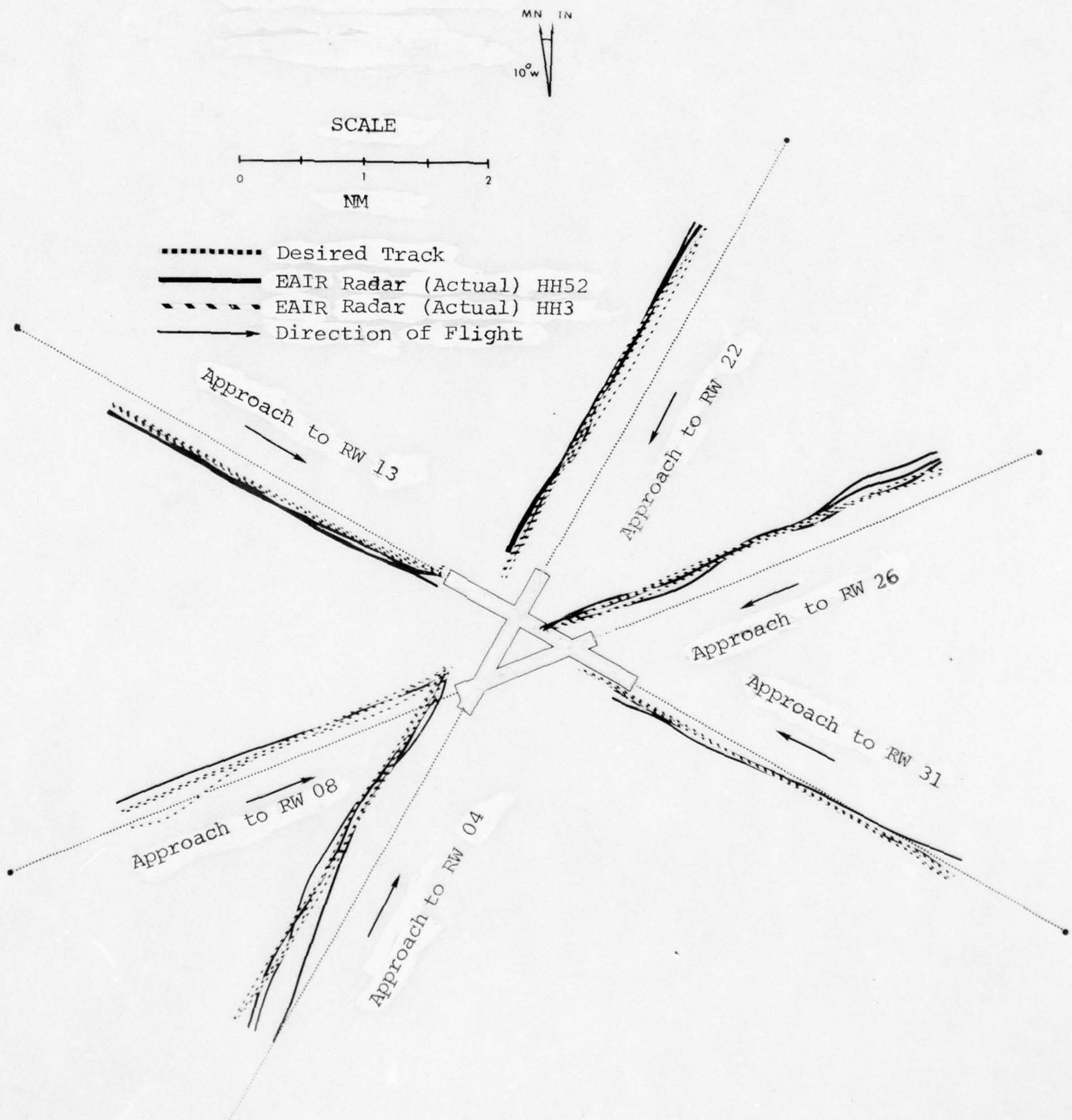

Figure 5.13 Multiple Runway Approach Data at NAFEC

Table 5.21 NAFEC Final Approach TSCT Summary (Production Navigator, 9960 Chain)

RUNWAY HEADING	HH3 (NON-UPDATED)		HH52 (NON-UPDATED)		AGGREGATE	
	Bias NM	±2σ NM	Bias NM	±2σ NM	Bias NM	±2σ NM
040°	-0.31	0.07	-0.26	0.24	-0.28	0.18
220°	0.29	0.07	0.32	0.07	0.31	0.08
080°	-0.08	0.12	-0.16	0.03	-0.10	0.13
260°	0.16	0.06	0.16	0.12	0.16	0.10
130°	0.15	0.04	0.16	0.06	0.16	0.05
310°	-0.11	0.04	-0.04	0.13	-0.08	0.12

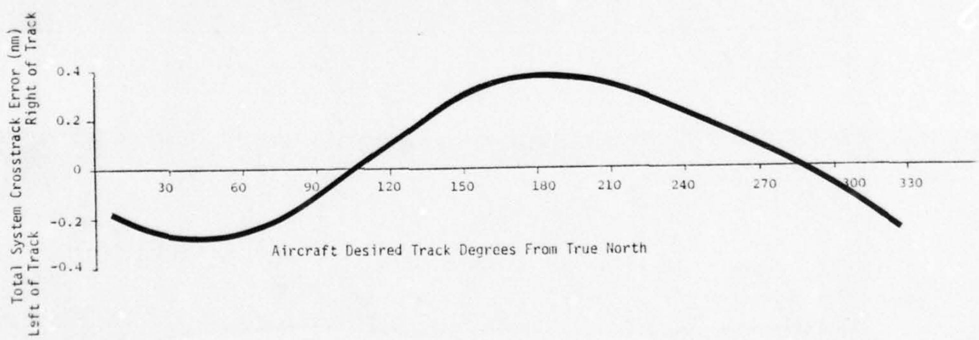

Figure 5.14 Behavior of Loran-C Bias Errors As A Function Of Course Bearing

In order to qualitatively assess the acceptability of Loran-C non-precision approach performance in other geometries, additional final approach tests were flown at Frederick, Maryland and Boston, Massachusetts. The NAFEC Loran-C geometry was relatively good. The Frederick, Maryland location is very close to the baseline of Seneca and Carolina Beach, N.C. The Boston, Massachusetts geometry is nearly coincident with the Nantucket secondary station.

At Boston, two types of approaches were flown. First, a Loran-C approach was made and tracked with the ARTS III radar similar to the NAFEC approach data taken by EAIR. Second, an ILS approach was flown and tracked by the ARTS III radar. The Loran-C indicated position was recorded during this approach as a substantiation of the Loran-C error data obtained during

the first approach. Table 5.22 presents the results of these two tests. It should be noted that each of the two procedures was flown three times to obtain the data shown in Table 5.22.

Table 5.22 Boston Approach Data

FLIGHT/TYPE	TSCT		FTE		ASE		POINTS
	Bias nm	±2σ	Bias nm	±2σ	Bias nm	±2σ	
1. Loran-C	.33	.13	.00	.14	.33	.05	41
2. Loran-C	.32	.06	-.01	.07	.33	.07	27
3. Loran-C	.31	.06	-.03	.06	.34	.05	34
AGGREGATE	.32	.10	-.01	.11	.33	.06	102
4. ILS	.02	.03	-.32	.05	.34	.06	26
5. ILS	.02	.02	-.34	.05	.34	.06	27
6. ILS	.02	.04	-.31	.03	.33	.06	23
AGGREGATE	.02	.03	.32	.05	.34	.06	76

Inspection of Table 5.21 shows several interesting facts regarding Loran-C accuracy. The data in the table shows Loran-C approaches (top half) and ILS approaches (bottom half). First, for the Loran-C approaches, Table 5.21 shows the repeatability of the navigator (TSCT mean errors of 0.33, 0.32 and 0.31 nm). Second, for the ILS approaches, Table 5.21 shows improved accuracy (TSCT mean errors of 0.02 nm). Finally, the Loran-C position data (ASE bias) recorded during the ILS approaches was 0.33 to 0.34 nm. This ILS data therefore, verifies the 0.32 TSCT aggregate bias obtained from the tracking radar. Interestingly enough, this one-third of a nautical mile TSCT was nearly identical in magnitude to the bias measured at NAFEC for both the production (-0.26 nm) and the prototype (0.38) navigators. This agreement in magnitude occurred with significantly different chain geometries for the production data using the 9960 chain and with the 9930 compared to the 9960 for the prototype data.

Frederick, Maryland did not have an ILS runway or ARTS III recording capability. Therefore, this approach data was limited to airborne Loran-C position data and observations by the pilot and test observer. Table 5.23 summarizes this qualitative accuracy estimate for two types of approaches. The first type was again a Loran-C approach and the indicated Loran-C position at the touchdown zone can be compared to visual observations. Second, a visual approach was flown and Loran-C position was recorded when over the touchdown zone.

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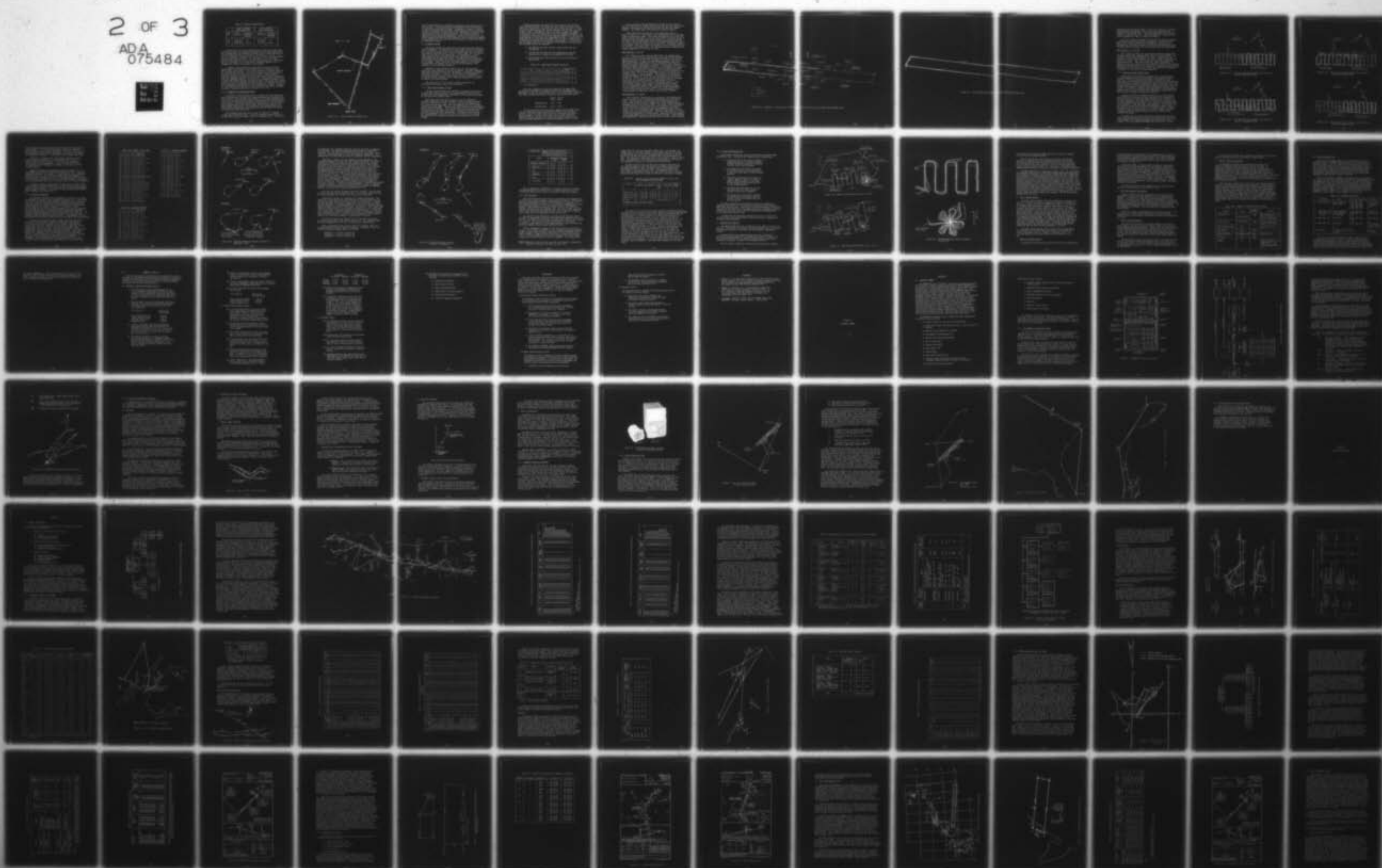

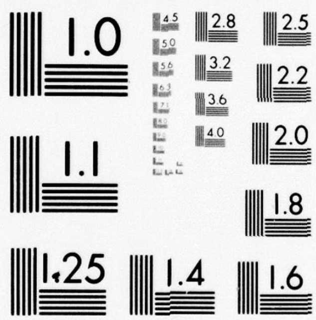

MICROCOPY RESOLUTION TEST CHART

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Table 5.23 Frederick Approach Data

	LORAN-C APPROACH Cross Track Error		VISUAL APPROACH Cross Track Error	
DTW NM	Loran-C Position	Observer's Estimated Position	Loran-C Position	Observer's Estimated Position
3.5	+0.44 nm	—	+0.11 nm	—
1.5	+0.09 nm	—	-0.14 nm	—
0.0	+0.05 nm	-0.25 nm	-0.17 nm	0.0 nm

Examination of the Loran-C approach data in Table 5.23 shows that based on the observer's estimated crosstrack position when hovering over the touchdown zone, the difference between actual aircraft position and Loran-C indicated position was again 0.3 nm (+0.05 to -0.25 nm). For the visual approach, the data is not exactly similar to previous approach accuracy from Boston or NAFEC. This data shows a -0.17 nm Loran-C position error when the aircraft is over the touchdown zone. Realizing the qualitativeness of using observer's estimates, however, this is probably well within the accuracy of the estimate.

In summary, the qualitative approach data collected at Boston, Massachusetts and Frederick, Maryland was similar in magnitude to the NAFEC system accuracy data. First, based on ARTS III tracking radar and on a centered ILS indicator, the Loran-C tracking error was estimated to be about one-third of a nautical mile at Boston. Second, based on observer's position estimates and Loran-C indicated position the Loran-C error was somewhere between 0.17 and 0.30 nm. These estimates provide an increased confidence that the EAIR approach data obtained at NAFEC is not unique to the Loran-C geometry relative to NAFEC. The Boston and Frederick data should not be interpreted to verify that Loran-C approach accuracy is 0.3 nm throughout the coverage area of the 9960 chain. Rather, it should be interpreted to indicate that at these locations, the Loran-C approach accuracy is probably closer to 0.3 nm than it is 1.0 nm.

5.2.5 Telemetry Tracking Demonstration

In addition to the AC 90-45A Loran-C accuracy data base obtained at NAFEC, the production navigator was used to demonstrate a telemetry data link function. This test was flown at NAFEC to illustrate possible applications (or integration) with current ATC procedures for the offshore oil rig operators. The Loran-C telemetry provides a plot of aircraft present position below normal surveillance radar coverage which could be used both onshore and offshore. The objective of this demonstration was to qualitatively examine the Loran-C downlinked position data with respect to the precision EAIR radar track.

The telemetered position data is shown in Figure 5.15 compared to EAIR data and desired track. It must be stressed that quantitative accuracy data cannot be attained from this telemetered data. The digital

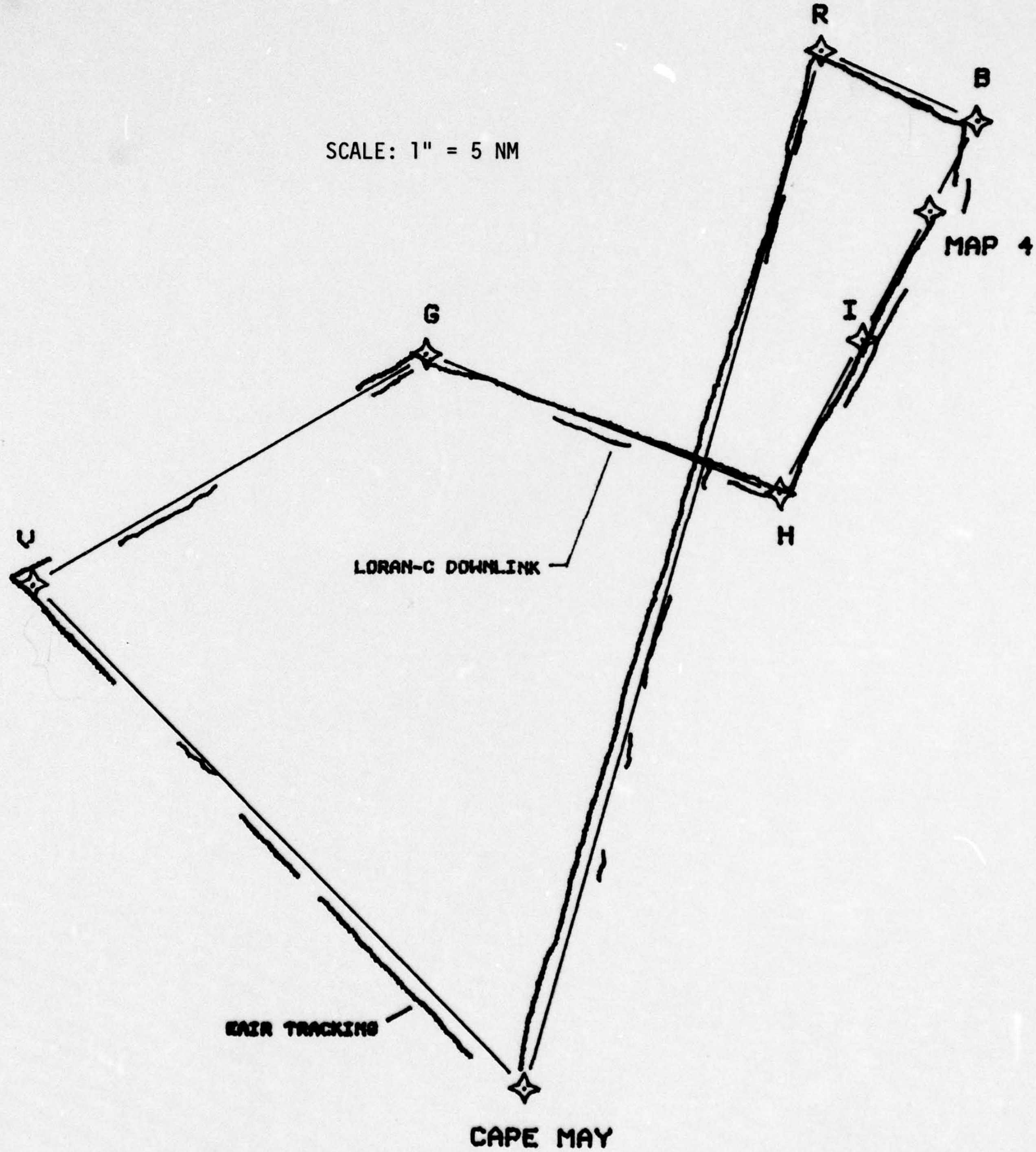


Figure 5.15 Loran-C Downlink Telemetry Test

tape of the telemetry test flight was accidentally overwritten prior to this analysis. The data shown was reconstructed from a plot obtained in real time during the test flight. Consequently, Figure 5.15 should be used to illustrate that downlink aircraft position data was obtained and that the accuracy of this data was not unreasonable relative to the actual aircraft track as measured by EAIR. The telemetry function demonstration was considered acceptable. However, the usability of this type of surveillance data for ATC purposes in such non-radar environments as the offshore oil rig areas must be determined by a significant amount of additional testing.

5.3 OFFSHORE TESTING

There were several test objectives to be satisfied which required flights overwater. The behavior of Loran-C signals and Loran-C accuracy out to the 200 nm limit of the Coastal Confluence Zone was of interest. This data was collected during a series of Deep Probes over the Atlantic Ocean off of Atlantic City, New Jersey. The existence of a Loran-C signal anomaly along the coastline had been hypothesized and was investigated both at dusk and at dawn. This data was collected during two creeping line patterns which criss-crossed the coastline along an 86 nm length. Other Loran-C data obtained offshore in the Atlantic included Search and Rescue tests to verify the performance of the production vs the prototype navigators.

Additional flight testing of Loran-C accuracy and functional capabilities was conducted in the Gulf of Mexico. Ship/Helo rendezvous tests were performed to assess any improvement in rendezvous procedures attainable with Loran-C. Finally, oil rig tests were performed to verify the ability of Loran-C to accurately guide an aircraft to rigs in various cluster densities and to illustrate repeatability accuracy for USCG surveillance purposes.

The results of all five of these offshore experiments are presented and analyzed in the following sections.

5.3.1 Deep Probe Overwater Testing

The deep probes offshore were performed to demonstrate operation of the Loran-C navigator during long range overwater missions and to document any signal propagation, functional or ATC operational problems in the execution of these flights.

Three deep probe tests were conducted using the AN/ARN-133 navigator installed in an HH3 helicopter. These tests were performed on 6-1,2 -1978 and on 11-7-78. The June tests were performed using the old East Coast Chain-9930, while the November tests was performed using the new chain-9960. The June tests were flown out to approximately 160 nm from the coastline. This section discusses the Loran-C accuracy, navigation signal strength and navigator operational problems which occurred during these three deep probes. Tracking data was obtained out to approximately 100 nm on each of these flights as was planned. No significant ATC coordination problems occurred during any of the flights.

Table 5.24 presents the statistical error analysis for the deep probe overwater testing. The reason for lack of any 6-1-78 data in the table was a problem which occurred with the airborne recorder. For this reason, the EAIR tracking data and the observer logs were the only data on this flight. Nevertheless, Table 5.24 shows a segment by segment comparison for all error quantities in the far offshore environment. It is significant that none of the errors measured exceeded ±0.3 nm and that large numbers of data points were aggregated (52-460). It should also be noted that the 6-2 data was on the 9930 chain and the 11-7 data was on the 9960 chain (398 and 341 data points, respectively). If the Bravo to New Era segment statistics are compared for the effect of the new chain, the following results are obtained:

1) The 9960 data was more accurate based on both TSCT and ASE measures.

2) The ATE with the 9960 chain was approximately the same magnitude but of opposite sign compared to the 9930.

3) Both flights were flown accurately by the pilot based on measured FTE.

Table 5.24 Deep Probe Overwater Statistics

WAYPOINTS	TSCT Bias NM	TSCT $\pm 2\sigma$ NM	FTE Bias NM	FTE $\pm 2\sigma$ NM	ASE Bias NM	ASE $\pm 2\sigma$ NM	ATE Bias NM	ATE $\pm 2\sigma$ NM	ATD NM	NUMBER OF POINTS	CHAIN	DATE
Bravo-New Era	-.2535	.0512	.0070	.0407	-.2605	.0334	.3223	.0241	74	398	9930	6-2-78
New Era-Charlie	-.0172	.0631	.0223	.0380	-.0395	.0595	.2999	.0394		65		
Bravo-New Era	-.0659	.0494	-.0325	.0471	-.0335	.0370	-.3790	.0236	74	341	9960	11-7-78
New Era-Charlie	.0957	.0648	.0012	.0261	.0946	.0679	-.4219	.0172		52		
Delta-Hotel	.0590	.0853	-.0028	.0351	.0618	.0792	.2688	.0254	200	460		

*ATD = Alongtrack Distance

Since the orientation of the test pattern for the deep probe was basically East-West, the behavior of the TSCT and ASE mean error magnitudes, as well as the ATE sign change, can be explained by examining the Loran-C northing and easting errors for the two different chains.

	6-2-78 9930	11-7-78 9960
Northing Error	-0.23	-0.07
Easting Error	-0.34	+0.38

Since the Northing error was greatly reduced with the 9960 chain, this was reflected in more accurate TSCT guidance along the basic Easterly course (TSCT went from -0.25 nm to -0.07 nm on the Bravo to New Era segment). Further verification that the TSCT change was largely due to the more accurate signals can be obtained by noting that FTE changed negligibly for these same segments (+0.01 to -0.03).

As was suspected from the behavior of the ATE (in this case an E-W error due to track heading), the Easting error was not significantly changed in magnitude but did change sign with the new chain (9960) geometry. As already noted, ATE tracked this behavior exactly.

A more qualitative perspective of the three deep probes is shown in Figure 5.16. This figure is an overlayed plot of all the radar tracks for the three flights. The figure substantiates the statistical results already discussed, in that all three tracks lie nearly on top of the desired course except where signal strength or navigator problems are noted. Due to EAIR dropout after 100 nm alongtrack distance, there is no aircraft track in Figure 5.16 for this data. Therefore, Figure 5.17 was prepared. This figure shows the airborne Loran-C indicated position for the 5.16 entire deep probe. The following discussion summarizes the flight sequence for 6-1, 6-2 and 11-7 data.

<u>Deep Probe No.1 - 6-1-78</u>

This flight was flown using the 9930 chain. No airborne data (Loran L/λ, DTW or XTK) was obtained due to airborne recorder problems. The precision EAIR tracking radar followed the flight out to 100 nm (New Era waypoint is 74 nm at sea and Charlie waypoint is 200 nm out). The flight actually progressed to 150 nm offshore before the pilot decided to reverse course due to a series of Loran-C warn lights and unfavorable weather (worsening visibility). As indicated in Figure 5.16, the Loran-C warn light turned on at 38 nm prior to New Era and stayed on for 24 nm (approximately 10 minutes). This indicated low signal to noise ratios (SNR's) which predominated during the remainder of the outbound flight. In fact, the warn light turned on at 100 nm prior to Charlie waypoint and remained on. The navigator was continually gaining and losing lock out to the turn around point at 90 nm-to-go to Charlie. At this point the aircraft was turned south to intercept the return leg from Delta to Hotel. Intermittent lock-on was experienced from 101 nm DTW to Hotel to 60 nm DTW to Hotel. Then at 43 nm DTW a Loran-C cycle jump was experienced which caused a 1.0 nm instantaneous change in ASE. The pilot elected to follow the new guidance and was able to complete the flight approximately 1.0 nm to the right of desired course. The pilot elected to fly a visual approach at NAFEC due to the Loran-C navigator problems.

<u>Deep Probe No. 2 - 6-2-78</u>

This flight was intended to be a reflight of the previous day's effort in order to try to complete the deep probe out to the 200 nm point. This flight was also necessary to establish whether the Loran-C problems were unique or repeatable. EAIR tracking data was obtained out to 110 nm on this flight. The flight actually progressed to 160 nm offshore at which time the pilot elected to intercept the return leg due to engine noises that were suspected to be slight surges. The Loran-C navigator again experienced weak SNR's at 74 nm and 64 nm to go to Charlie waypoint. The warn light turned on at 48 nm to Charle and remained on for two minutes. Upon acquiring the inbound course, weak SNR's occurred at the 128 nm DTW to Hotel. EAIR tracking was reacquired at 103 nm to go to Hotel and no further Loran-C dropouts

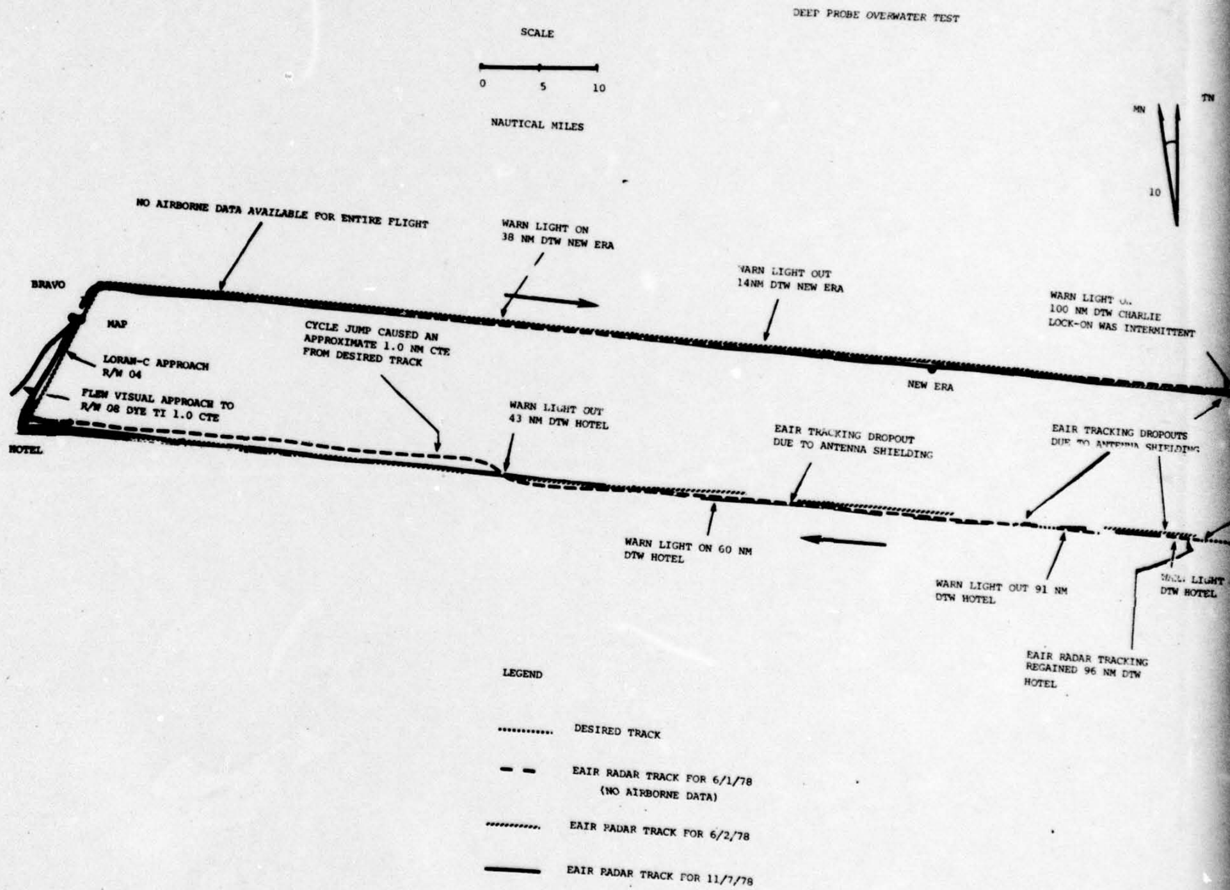
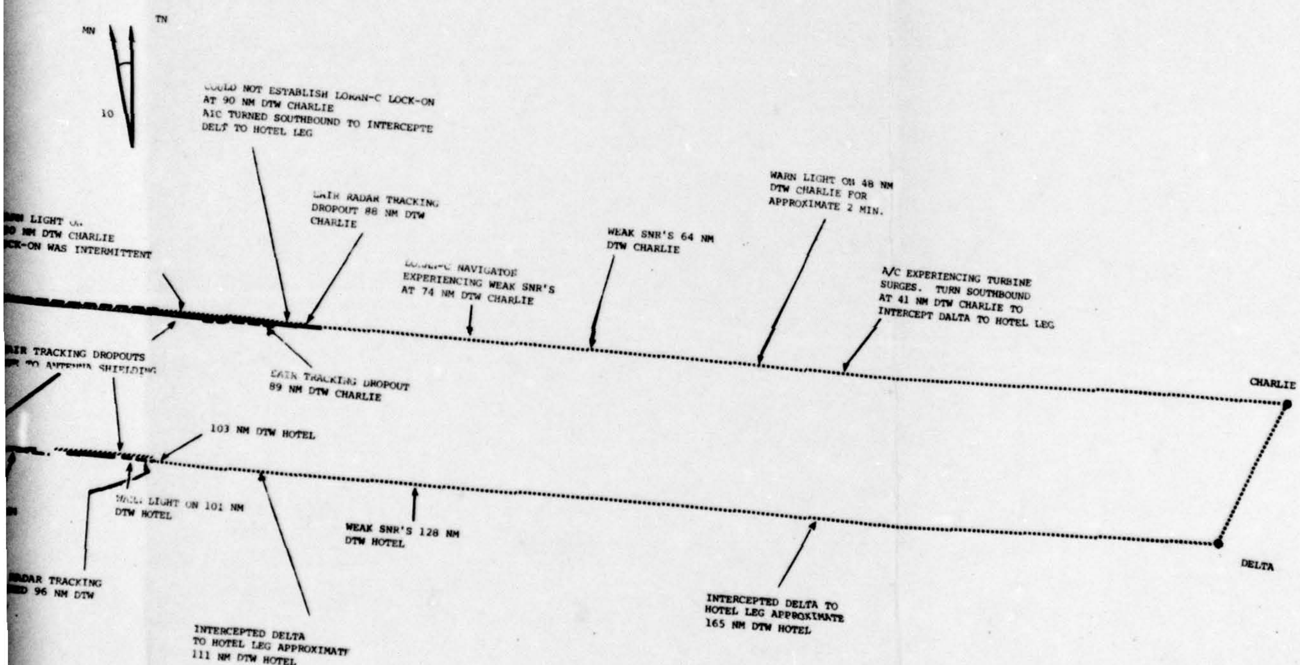


Figure 5.16 Composite of Three Aircraft Flight P



raft Flight Paths During Deep Probe Overwater Tests

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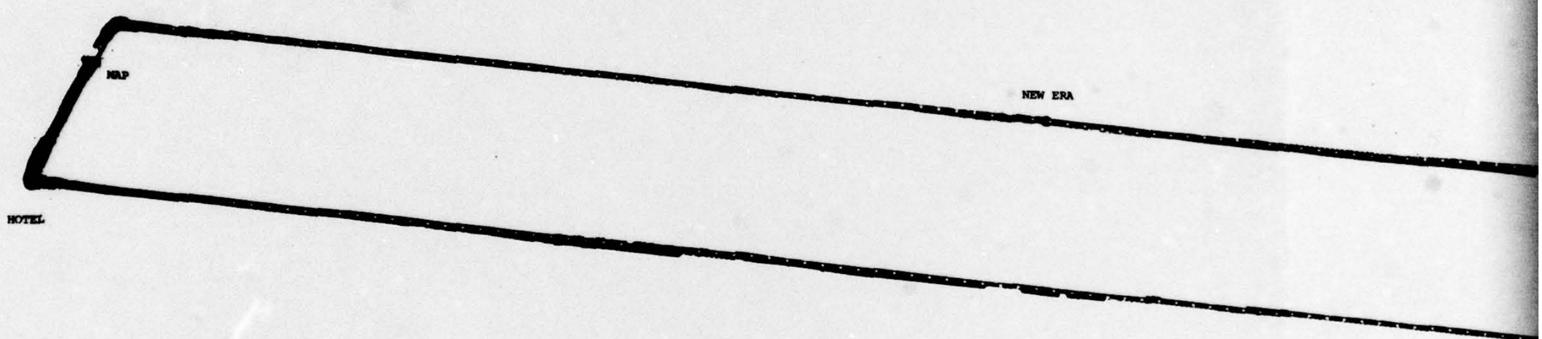
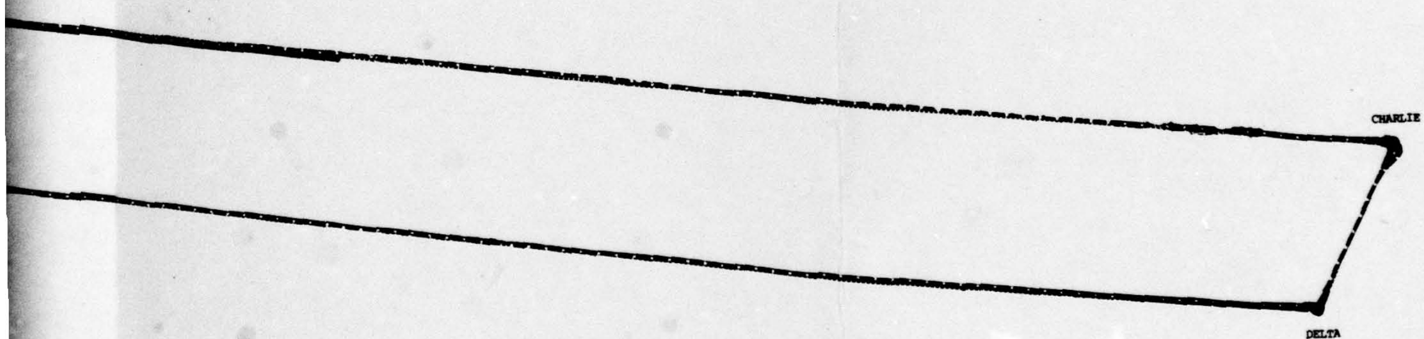


Figure 5.17 Loran-C Deep Probe Positi



oran-C Deep Probe Position Data

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104x

occurred during the return flight. This can be observed by carefully inspecting the crosshatched line on Figure 5.16 compared to the previous flight (dashed line). Several problems did occur with EAIR dropouts as noted on the plot. Upon reaching Hotel, a non-precision Loran-C approach was flown to runway 04 at NAFEC.

Post test inspection revealed that the Loran-C antenna grounding system used on the HH3 aircraft was inadequate. The HH3 was sent back to Otis, AFB to redesign the installation and the Loran-C navigator was installed in an HH52 aircraft for continued evaluation. The deep probe was reflown after the new 9960 chain was commissioned.

Deep Probe No. 3 - 11-7-78

This flight was flown with a new antenna grounding system which provided significantly improved SNR's even on the ramp at NAFEC. The flight was flown using the 9960 Loran-C chain. EAIR tracking was continuous out to 110 nm offshore. No Loran-C signal losses occurred during this flight. SNR's were strong out to the 200 nm offshore waypoint (Charlie). The return flight was equally uneventful. As previously shown on Figure 5.16 and in Table 5.24, the aircraft tracking accuracy was extremely good with outbound and inbound mean and two-sigma TSCT errors of less than 0.1 nm. Loran-C was, therefore, considered acceptable for this type of offshore operation.

5.3.2 Coastline Signal Anomaly Tests

These tests were structured to obtain data on the postulated overland/overwater transition anomaly which could impact Loran-C accuracy. The tests included two flights in the HH52 aircraft. A dawn creeping line pattern was flown back and forth along the coastline on 12-18-78 and a comparable pattern was flown at dusk on 1-19-79. The primary objective of these tests were to define and document the extent to which the land/water interface affects navigation accuracy using Loran-C. In order to accomplish these objectives it was necessary to examine both the actual aircraft track information obtained from EAIR and the Loran-C airborne indicated position data.

Figures 5.18 and 5.19 present the entire set of EAIR tracking data collected for the dusk and dawn coastline tests, respectively. The actual aircraft tracks are shown overlayed on the coastline. A cursory inspection of this data leads to the correct conclusion that no signal anomalies were observed. This conclusion was substantiated by the observer's logs and flight crew commentary. In addition, this was verified by the CDI deflection data recorded. However, due to the speed of the aircraft or the scale of these figures, it might be possible to miss an actual anomaly. Therefore, several coastline crossing points were examined carefully to try to discover the hypothesized anomaly.

In Figure 5.18 (a) and (b) the Loran-C airborne data recorded every three seconds was scrutinized for discontinuities at each land/water boundary. No significant changes were discovered. As an examples, the route segment marked ⓐ - ⓐ in Figure 5.18a included

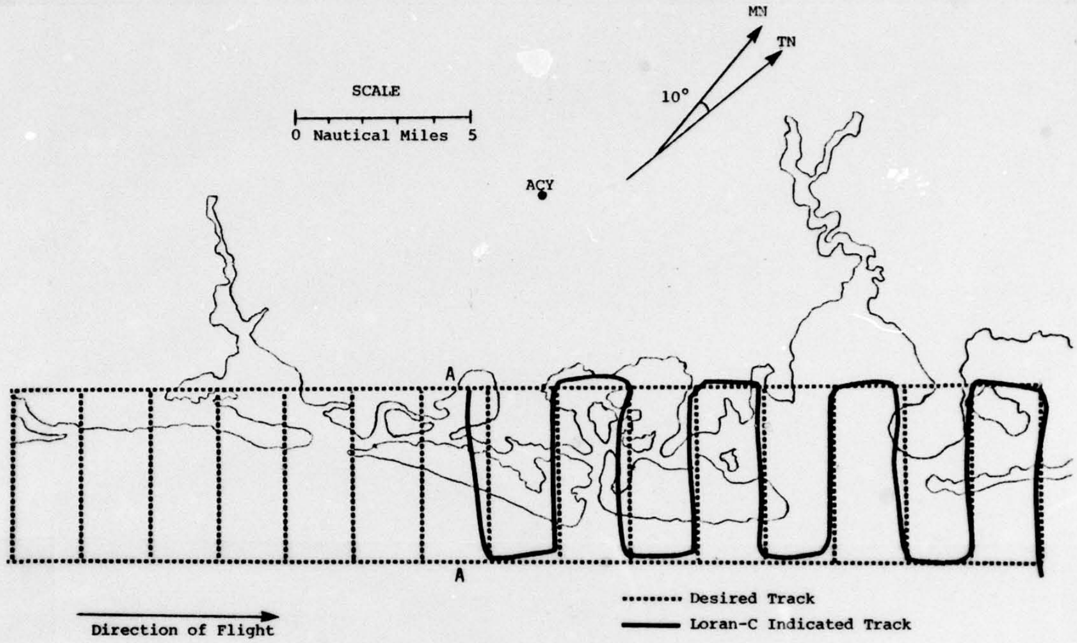

Figure 5.18 a. Dusk Coastline Signal Anomaly Test Profile of Loran-C Indicated Position

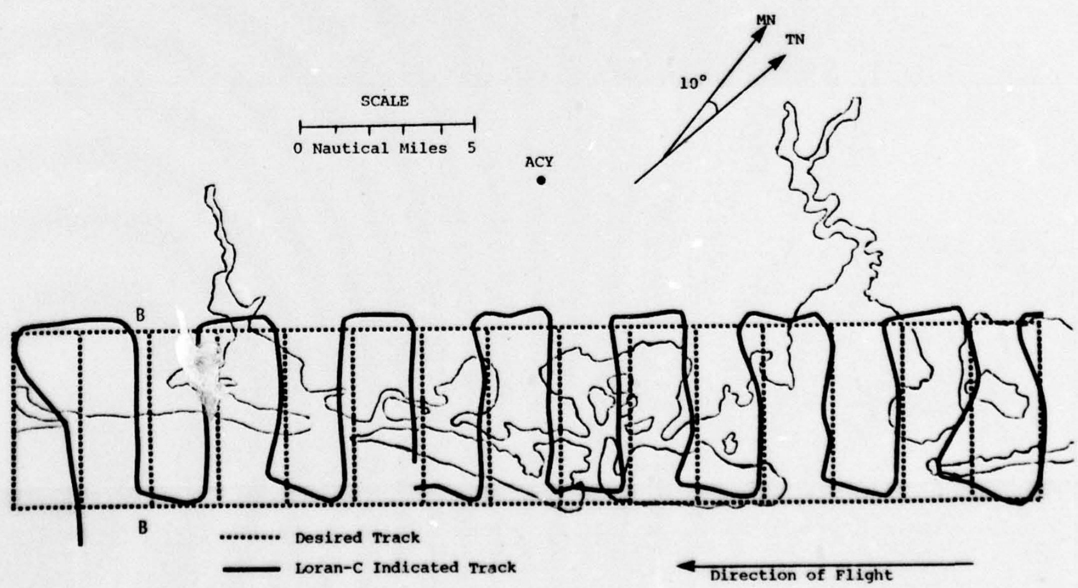

Figure 5.18 b. Dusk Coastline Signal Anomaly Test Profile of Loran-C Indicated Position

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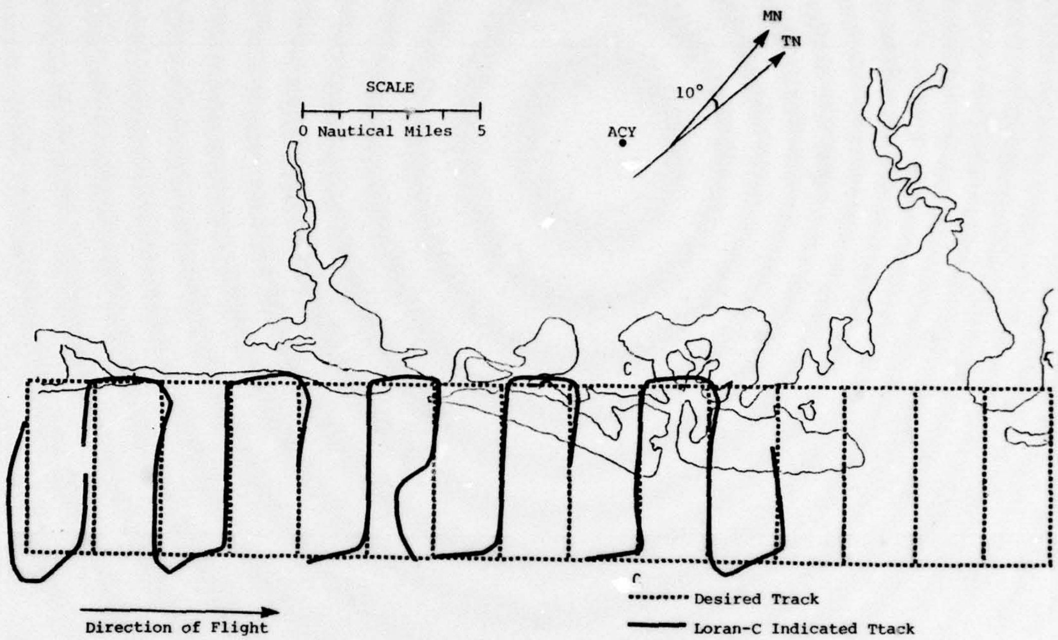

Figure 5.19 a. Dawn Coastline Signal Anomaly Test Profile of Loran-C Indicated Position

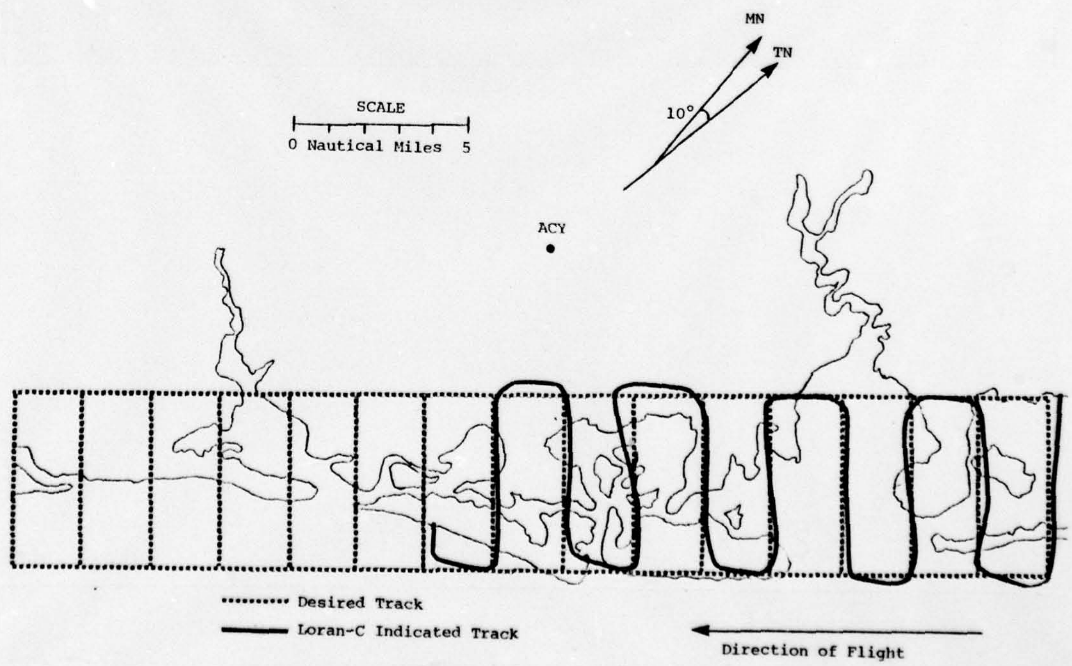

Figure 5.19 b. Dawn Coastline Signal Anomaly Test Profile of Loran-C Indicated Position

four land/water interfaces with the initial transition from water to land at point 1. The lat/lon data shown in Table 5.25 shows no discontinuities at any of these interfaces. This fact is verified by the consistently centered CDI (CTD changed less than .05 for each of the land/water interfaces). In addition, no ATD changes were noted.

Similarly, in Figure 5.18b, leg ⓑ - ⓑ has two minor and one major land/water transitions. In this example the aircraft is transitioning from land to water. Table 5.26 shows continuous lat/lon data for this segment also. Table 5.26 CTD and ATD data is continuous for all land/water interfaces as was the case in the previous example.

Figure 5.19a shows an excellent test segment labeled ⓒ - ⓒ. On this segment the aircraft is proceeding from land to water. The major land/water interface is at point 2. Lat/Lon data for this interface is shown in Table 5.27. No significant discontinuity was observed. On the dawn flight of Figures 5.19a and b, the airborne recorded data was not continuously available due to a data recording problem. Consequently, cross track deviation data can not be checked for all of these interfaces.

In summary, based on an analysis of actual aircraft tracking data, lat/lon Loran-C data and CTD/ATD data, no significant coastline signal anomalies were discovered. This conclusion was verified by the graphical data presented in Figures 5.18 and 5.19 as well as the example tabular data in Tables 5.25, 5.26 and 5.27.

5.3.3 Ship/Helo Rendezvous

The ship/helo rendezvous test encompassed 17 flights for 2.0 hours as described in Figure B.19 and discussed in Section B.1.3. The results of this test were derived from airborne recorded data and the observers logs only, since no tracking facility was available in the test area. Figures 5.20 and 5.21 present the airborne flight path of the aircraft as calculated by the Loran-C navigator. Five of the 17 flights are not shown due to lack of necessary airborne data from the navigator. This data was lost due to excessive workload requirements inputting Loran-C navigation data prior to the pilot beginning the rendezvous. The ship/helo rendezvous approaches were conducted to a stationary buoy although a ship had been secured for the test. Unfortunately, the ship was diverted for a priority surveillance activity during the testing period.

The test was divided into three approach techniques and will be discussed in a chronological sequence. Technique 1 was composed of five approaches (four complete and one attempt) illustrated in Figure 5.20. The first approach was interupted by "WARN" and "ADVISE" lights indicating "not in track", "float" and "secondary change recommended". After the copilot placed the navigator in the initialize mode, signal strength came back up to operating level. Approaches 1 through 5 of Technique 1 were accomplished using the display hold function of the navigator to create a waypoint for the buoy's position, and the standard USCG ship/helo rendezvous and beep-to-hover procedures. After completing the tear-drop and stabilized on wind line (65° true), the aircraft was approximately 1.4 nm from the buoy

Table 5.25 Segment ⓐ - ⓐ Dusk

LAT	LON	CTD (nm)	ATD (nm)	
39° 19.97'	74° 24.26'	R.16	1.09	
39° 20.08'	74° 24.22'	R.11	0.97	Water
39° 20.20'	74° 24.19'	R.04	0.87	
39° 20.31'	74° 24.18'	L.02	0.77	
39° 20.42'	74° 24.14'	L.05	0.67	
39° 20.52'	74° 24.06'	L.05	0.54	Land
39° 20.61'	74° 23.94'	L.03	0.42	
39° 20.69'	74° 23.83'	L.02	0.30	
39° 20.78'	74° 23.73'	L.03	0.19	← Leg Change
39° 20.87'	74° 23.66'	L.07	4.97	
39° 20.96'	74° 23.56'	R.05	4.95	
39° 21.07'	74° 23.52'	R.15	4.88	Water
39° 21.20'	74° 23.53'	R.20	4.78	Land
39° 21.30'	74° 23.64'	R.20	4.63	
39° 21.37'	74° 23.80'	R.16	4.48	
39° 21.42'	74° 23.99'	R.07	4.25	Water
39° 21.50'	74° 24.25'	R.04	4.15	
39° 21.56'	74° 24.37'	R.03	4.05	

Table 5.26 Segment ⓑ - ⓑ Dusk

LAT	LON	CTD (nm)	ATD (nm)	
39° 13.21'	74° 35.59'	R.14	4.17	
39° 13.30'	74° 35.71'	R.14	4.03	
39° 13.40'	74° 35.86'	R.14	3.88	Water
39° 13.49'	74° 36.02'	R.13	3.73	
39° 13.57'	74° 36.18'	R.10	3.57	
39° 13.64'	74° 36.34'	R.08	3.45	
39° 13.71'	74° 36.50'	R.04	3.31	
39° 13.77'	74° 36.65'	R.02	3.17	Land
39° 13.85'	74° 36.80'	R.01	3.03	
39° 13.94'	74° 36.92'	R.05	2.90	
39° 14.06'	74° 37.03'	R.09	2.76	

Table 5.27 Segment ⓒ - ⓒ Dawn

LAT	LON	
39° 29.44'	74° 24.82'	
39° 29.16'	74° 24.73'	
39° 28.92'	74° 24.46'	Land
39° 28.77'	74° 24.08'	
39° 28.66'	74° 23.74'	
39° 28.53'	74° 23.43'	
39° 28.36'	74° 23.18'	
39° 28.19'	74° 22.90'	
39° 28.02'	74° 22.60'	Water
39° 27.85'	74° 22.30'	
39° 27.68'	74° 21.98'	
39° 27.50'	74° 21.66'	
39° 27.31'	74° 21.38'	
39° 27.10'	74° 21.11'	
39° 26.90'	74° 20.82'	Land
39° 26.71'	74° 20.53'	
39° 26.51'	74° 20.26'	

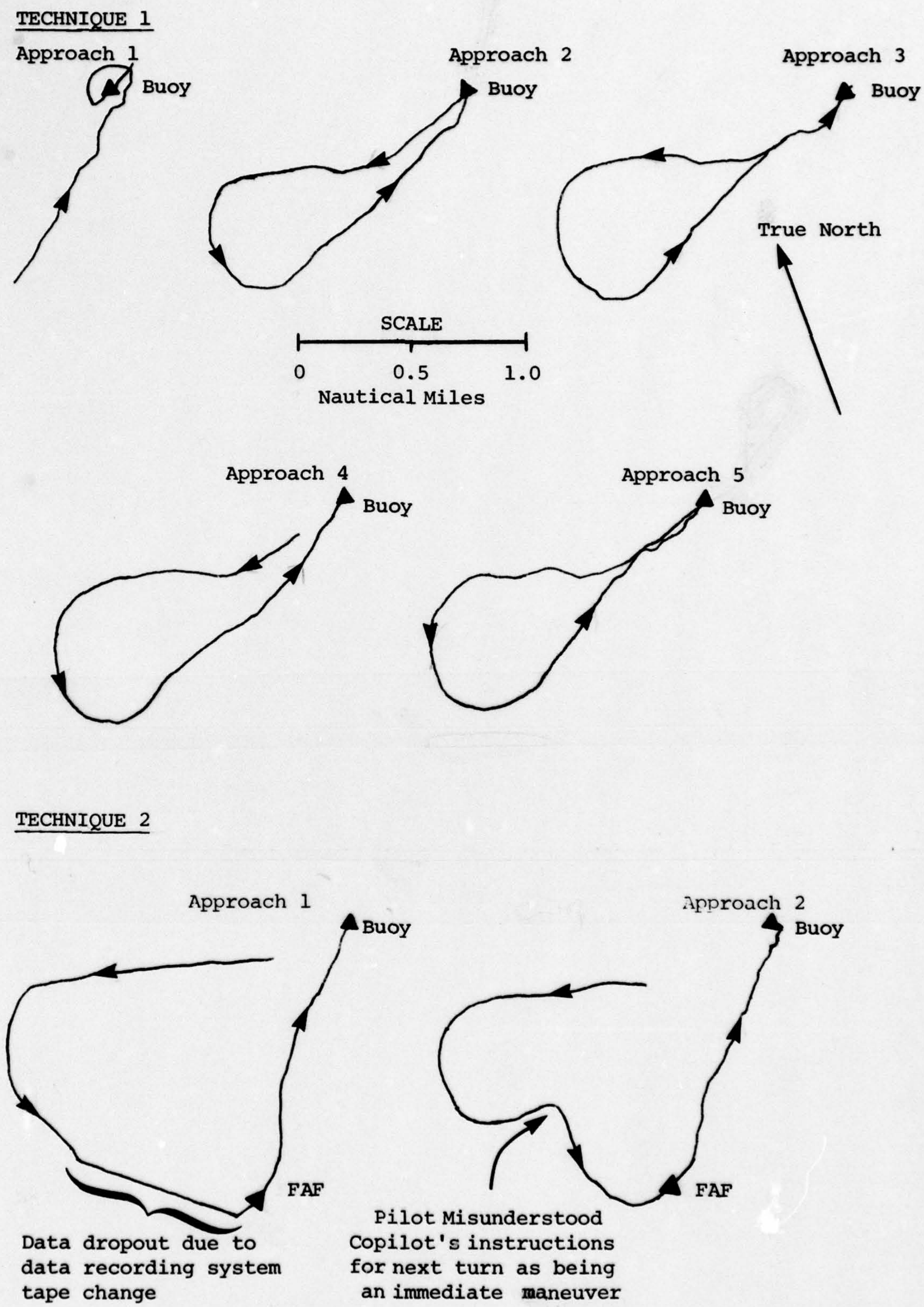

Figure 5.20 Ship/Helo Rendezvous Approach Profiles for Techniques 1 and 2

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for approaches 2-5, providing sufficient time for the pilot to complete each approach. The complete rendezvous required about 4 minutes per approach. The pilot and copilot confidence level was described as being "very high" and the workload as "low" for Technique 1 approaches. The headdown time for the pilot and copilot was about 5% and 10%, respectively.

Technique 2, Figure 5.20, was composed of seven approaches, five imcomplete attempts (not shown) and two complete approaches. Technique 2 incorporated the USCG standard ship/helo rendezvous and beep-to-hover procedures with extensive Loran-C navigator utilization. The intended procedure was for the copilot to create the buoy position first with the display hold function, then create the FAF waypoint while the pilot proceeded downwind. The first attempt failed due to the inability of the copilot to provide navigation for the pilot to the FAF prior to coming to the first turn. The second attempt (Approach 1) was completed in approximately 7 minutes. The third and fifth attempts failed due to the copilot's inability to provide navigation prior to the pilot making the 40° turn from downwind. Attempts four and six failed because the copilot incorrectly calculated the FAF waypoint with the navigator's rho, theta function. The seventh attempt (Approach 2) required approximately 6 minutes to complete. During the teardrop maneuver, the pilot misunderstood the copilot's instructions for the next turn as being an immediate maneuver, deviating from course by approximately 0.3 nm.

The pilot and copilot confidence level for Technique 2 was described as being "very low" and the workload level as "very high", requiring about 5% and 95% headdown time for the pilot and copilot respectively.

Technique 3, Figure 5.21, consisted of 5 complete approaches. This technique utilized the display hold function to create the buoy position and the rho, theta function to create the FAF as in Technique 2. However, straight departure and approach segments were used rather than the USCG tear-drop maneuver. It was determined that 1.7 nm was an adequate approach segment distance from the FAF to the buoy. Approaches 1, 2 and 3 were flown along the windline with a final approach leg heading 65° true. Approaches 4 and 5 were flown at heading perpendicular to the windline, 155° and 335° true, respectively. There is a general indication of improvement through each successive approach. Except for the first approach, which required 7 minutes, all others were completed in approximately 5 minutes.

The pilot and copilot confidence level for Technique 3 approaches were described as being "high" and the workload as "low", demanding about 5% and 15% headdown time, for the pilot and copilot, respectively.

Table 5.28 summarizes the pilot and copilot confidence level and workload assessment for each approach technique. A summary of the pilot and copilot percent headdown time is as follows:

Technique 1 - Pilot 5%, Copilot 10%
Technique 2 - Pilot 5%, Copilot 95%
Technique 3 - Pilot 5%, Copilot 15%

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TECHNIQUE 3

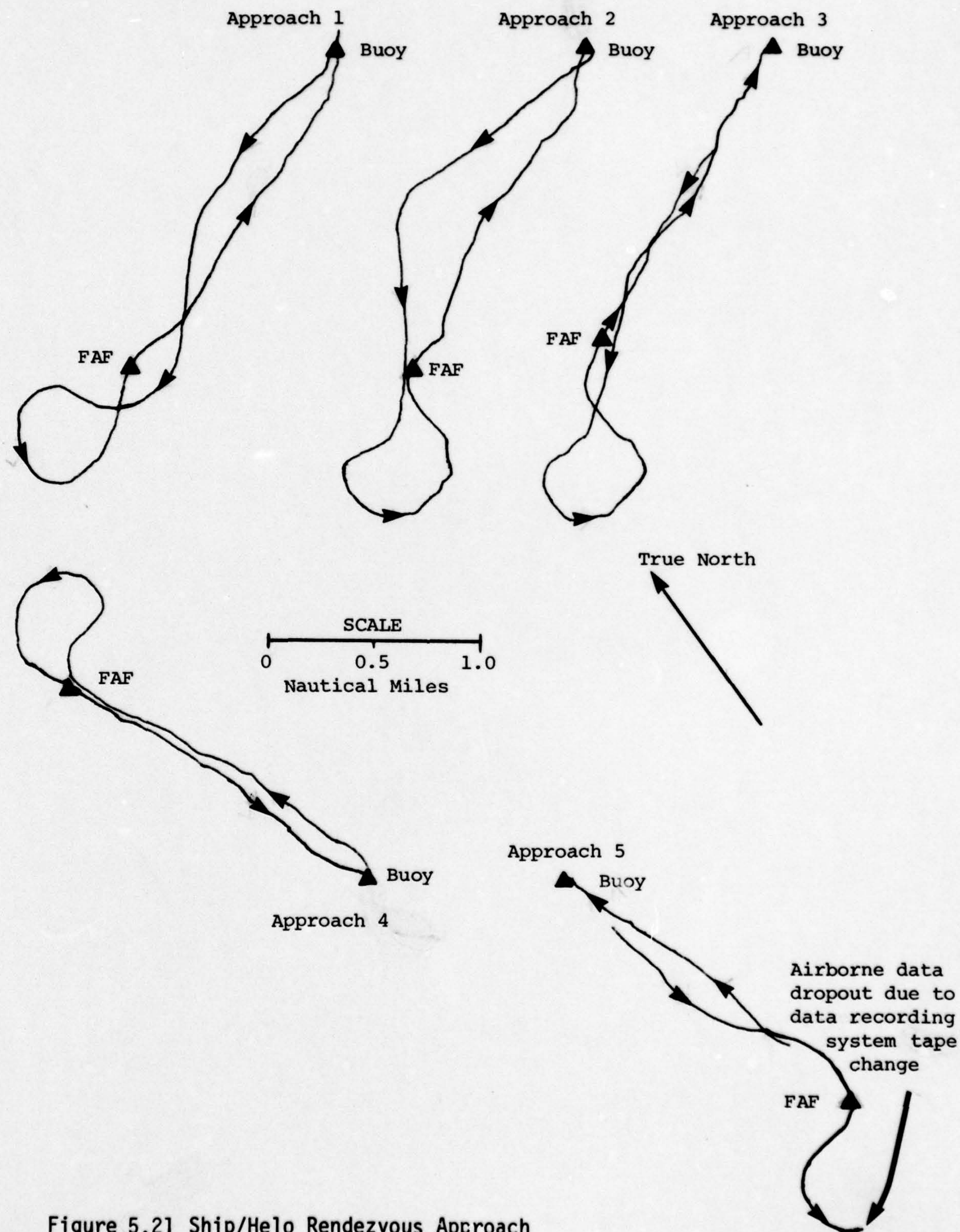

Figure 5.21 Ship/Helo Rendezvous Approach Profiles for Technique 3

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Table 5.28 Summary Of Pilot And Copilot Confidence And Workload Level For The Ship/Helo Rendezvous Test

SCALE	CONFIDENCE LEVEL			WORKLOAD LEVEL		
APPROACH TECHNIQUE:	1	2	3	1	2	3
Very Low		X				
Low				X		X
Moderate						
High			X			
Very High	X				X	

For all approaches, regardless of workload, the Loran-C navigator provided navigation to the buoy with an average accuracy of 0.01 nm in CTD and 0.04 nm in ATD, relative to the FAF to Buoy route segment.

5.3.4 Oil Rig Tests

This section presents the results of the accuracy and repeatability testing of the Loran-C navigator's applicability to the U.S. Coast Guard's surveillance/enforcement mission and the offshore oil industry. As previously described in Section 3.3.4, accuracy and repeatability testing was performed on three oil rigs in the Gulf of Mexico near Mobile, Alabama. Approximately four minutes of data in lat, lon and TD's was acquired for each rig on two separate days. The Loran-C East Coast 9930 chain in the update mode was used for this test, as the Gulf of Mexico chain (7980) was not in scheduled service at that time.

The results of the offshore oil rig tests verify that the Loran-C navigator is operationally accurate with significant repeatability to aid the U.S. Coast Guard on surveillance and enforcement missions and offshore oil industry. The Loran-C navigator demonstrated the capability to define a target position in latitude/longitude or time differences by using the display hold of present position function.

Table 5.29 presents a summary of the accuracy data in the form of 2 d_{rms}. Also defined in the table is the surveyed latitude and longitude of the oil rigs tested and their respective distances from Bates Field, Mobile, Alabama. 2 d_{rms}* defines the radius of a circle where there is a 95.4% to 98.2% probability of locating a target within an associated 2 d_{rms} error in feet, for each rig or all combined. The 2 d_{rms} errors

/NOTE/ *Measures of Error in Loran and their Relationship to Geometrical Dilution of Precision, No. 6449, June 29, 1973.

(113)

ranged from 114.4 feet to a maximum of 507.0 feet. For example, the 2 d_{rms} error of 114.4 feet defines a circle whose radius is 114.4 feet in which there is a 95.4% to 98.2% probability of locating the Chevron MP 41C oil rig when the Loran-C navigator reads CTD and DTW equal to zero. The statistical combination of all rigs yields of 2 d_{rms} of 1698.3 feet. The magnitude of this data should be considered in the light of the subsequent discussion of possible contributing errors.

The Mean Position Error in Table 5.29 represents the ability of the Loran-C navigator to provide guidance to a known position within an associated error in feet. The Mean Position Error ranged from 598.4 feet to a maximum of 2478.3 feet. The aggregate data of all rigs reveals a Mean Position Error of 1505.9 feet (0.248 nm), slightly smaller than the specified tolerance (0.250 nm) of the Loran-C navigator.

Table 5.29 Loran-C 2 d_{rms} Accuracy Of Tested Oil Rigs In The Gulf Of Mexico With Chain 9930

Oil Rig I.D.	Latitude (Degree, Min.)		Longitude (Degree, Min.)		Mean Position Error (feet)	2 d_{rms} (feet)	Data Points	Distance* Offshore (nm)
Chevron 107 A	29°	32.5333'	88°	43.6167'	1389.2	378.9'	23	73.6
Chevron MP 299 D	29°	15.1667'	88°	45.4500'	2478.3	507.0'	21	90.6
Chevron MP 41 C	29°	23.9000'	89°	00.7333'	598.4	114.4'	17	87.6
All Rigs	—	——	—	——	1505.9	1698.3'	61	—

***Distance from Bates Field, Mobile, Alabama**

This leads into a discussion of four possible contributing errors to the data analysis. One error contributor might be in the latitude/longitude coordinates of the helipad at Bates Field, which the navigator used for position update. The helipad position as derived from the chart is believed to be accurate to within ±0.03 nm. Another contributing factor would be the accuracy of the surveyed positions of the oil rigs. The magnitude of the Mean Position Error of Chevron MP 299 D as was noted on two separate days, indicates a possible surveying error or a published typographical error. The other two oil rigs are within the Loran-C navigator tolerances for 2 d_{rms}. The third contributing error factor is represented in the position where the aircraft hovered relative to the actual position of the oil rig. In all cases, the aircraft was visually estimated to be within 60 feet laterally and 20 feet vertically of the desired oil rig. The fourth contributing error may be associated with the use of the East Coast 9930 chain. It is anticipated that the Gulf of Mexico chain would provide improved results intrinsic with its geometry. In light of these other error sources, the navigator can be considered to have performed acceptably during these tests.

5.3.5 Search and Rescue Tests

This section presents the results of the Search and Rescue (SAR) operational tests. Discussion will identify the following areas:

1) A qualification of the Loran-C navigator's operational ability to provide automatic guidance during the execution of Creeping line and Sector Search patterms.

2) The capability of the Loran-C navigator to provide guidance to and resume search at the exact point where it had previously departed.

3) The ability of the Loran-C navigator to create a waypoint from a rho, theta of a waypoint being navigated to, and then provide guidance from present position to the created waypoint.

4) The operational characteristics of the continuous parallel offset guidance feature of the Loran-C navigator.

5) The capability of the Loran-C navigator to provide direct-to guidance from the parallel offset cancellation point to a desired waypoint.

The data processing for the SAR test results was performed by presenting the actual aircraft position information provided by NAFEC EAIR radar tracking plots. Qualification and interpretation of deviations from the desired track due to equipment malfunction, equipment functional limitations, procedural errors and pilot workload were substantiated by the flight test observer logs.

It should also be noted that although the crew was briefed prior to the testing, they had no inflight training for Loran-C creeping line and sector search execution.

A. Creeping Line Patterns

Two identical SAR tests were performed and are shown in Figures 5.22 and 5.23. Discussion will consider each test separately due to particular circumstances involved in the latter test which greatly affected the results.

Accurate results were demonstrated by the Loran-C navigator's ability to provide guidance for the Creeping Line Pattern, Figure 5.22. This substantiated the results previously demonstrated by the Loran-C navigator, illustrated in Figure 5.24, reference CG-D-9-77.

Only one Loran-C operational problem occurred during the Creeping

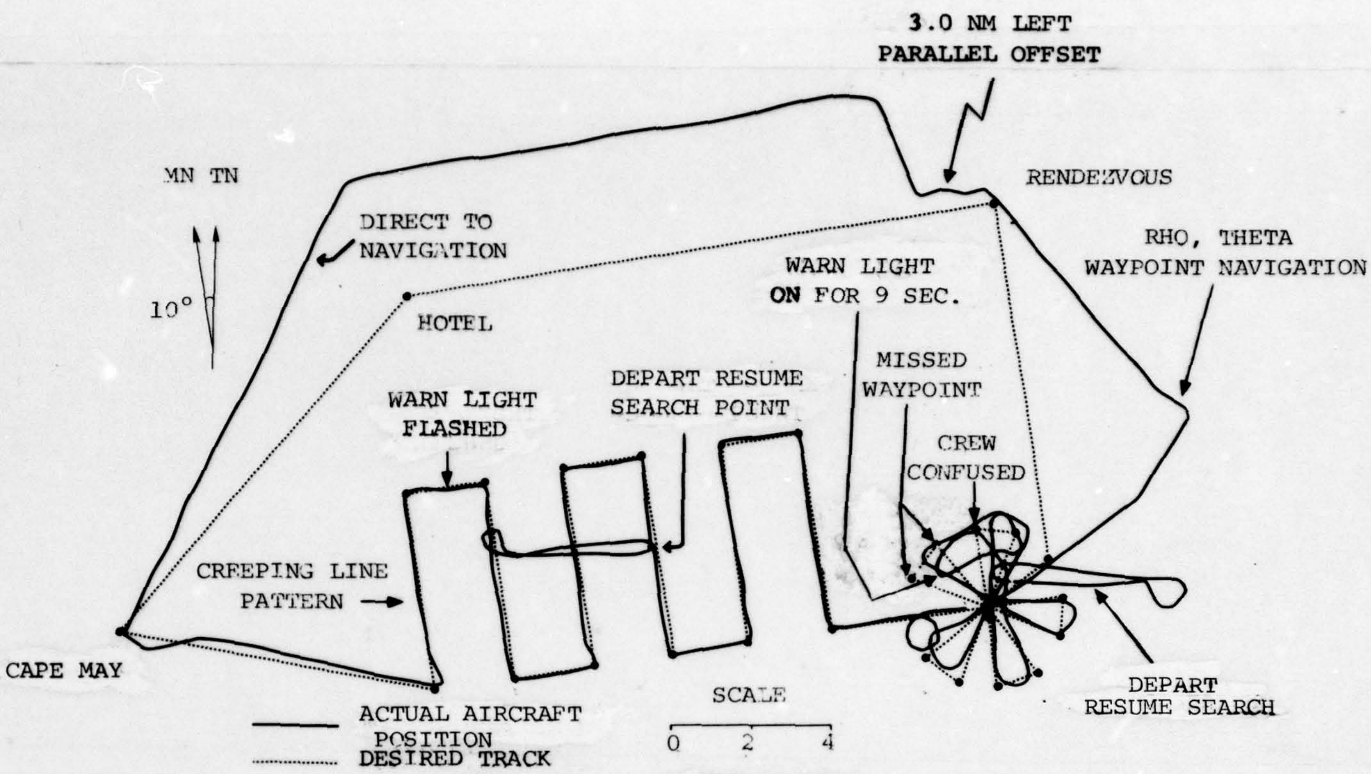

Figure 5.22 Search and Rescue Mission Test of 6-13-78

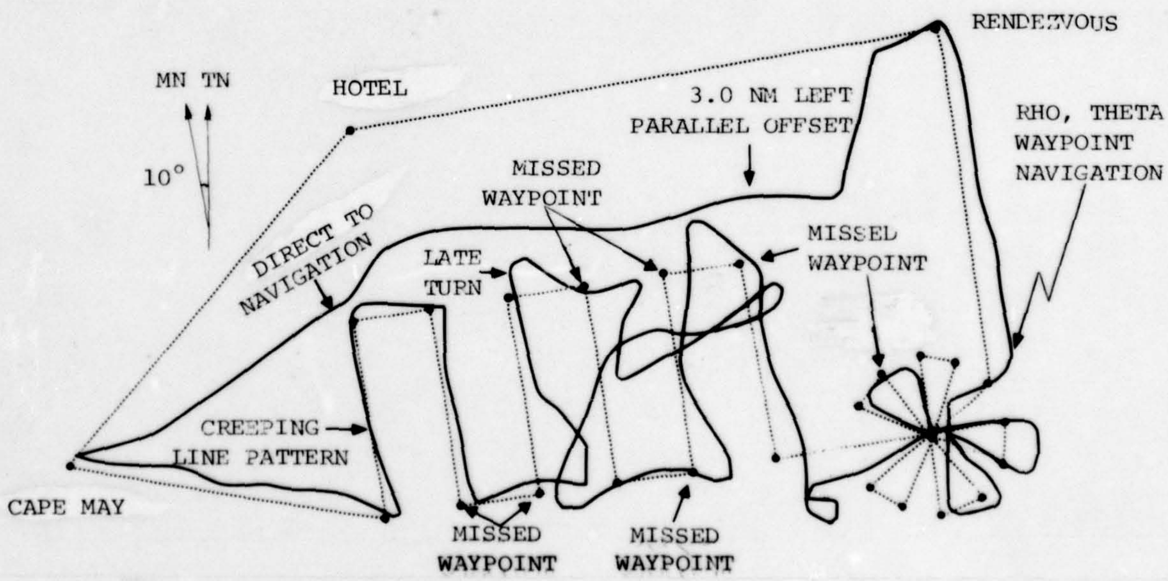

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Figure 5.23 Search and Rescue Mission Test of 7-11-78

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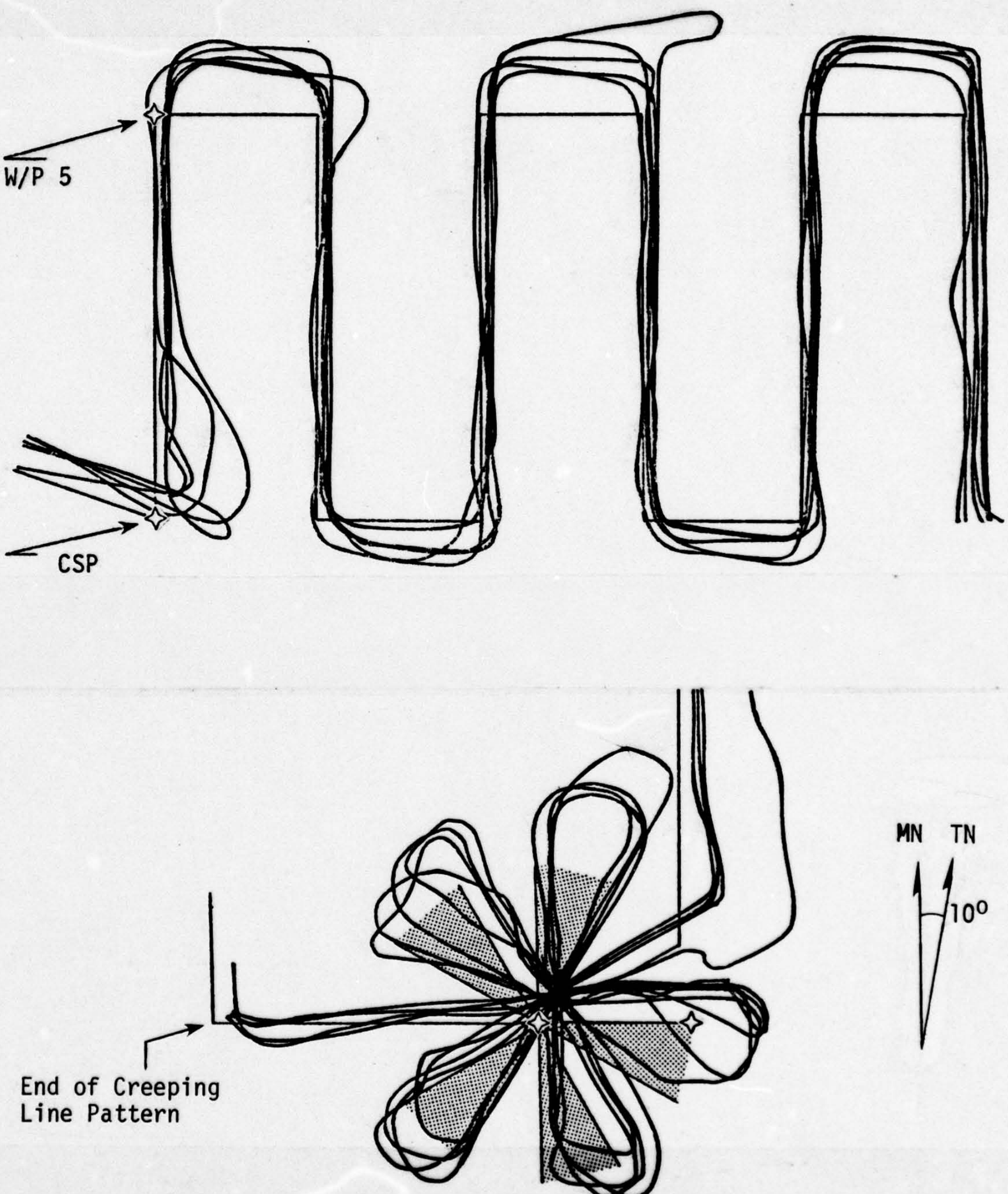

Figure 5.24 Prototype Navigator Search and Rescue Mission Data

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Line Pattern which involved a WARN light flash on pattern 1, segment 2,3, but did not disturb navigation.

The only operational problem that occurred which affected the execution of creeping line was a programming error by the copilot. The error caused the entire creeping line and sector search patterns to be shifted 10° East from true north. This, of course, would have greatly affected desired probability of detection. The patterns were shifted exactly 10° West to align with true north for graphic presentation.

The second SAR test is illustrated in Figure 5.23. This test experience apparent strong Loran-C signal interference throughout indicated by the navigator's scalloped course guidance information, but no WARN lights were encountered. Of the 25 waypoints used during the test, seven were missed due to large CTE and DTW fluctuations by as much as 0.25 nm. Six waypoints missed were in the creeping line pattern. This resulted in the workload becoming very high, with copilot headdown time about 80%, due to overflying waypoints, late turns, and having to execute manual leg changes. Investigation produced two possible interference sources. The first is the frequent radio transmissions from Annapolis. The second and more likely was confirmed by the Space Environment Laboratory, ERL, in Boulder, Colorado. On the date of this test at 1700Z a solar flare level was recorded in excess of X15, one of the largest ever recorded. The SAR test occurred between 1500Z and 1703Z.

B. Sector Search Patterns

The Sector Search Patterns were also illustrated in Figures 5.22 and 5.23. Figure 5.22 displays a significant amount of workload for the copilot, (about 95%) after the WARN light came on. The occurrence of the WARN light on pattern 1, segment 3,4 was the only Loran-C navigator operational problem during the sector search. This WARN occurred approximately 0.26 nm prior to the waypoint change and lasted about nine seconds. Since the aircraft had passed over the waypoint, when navigation was reacquired the waypoint had not sequenced. By the time this was discovered and a manual leg change was executed the next waypoint had been passed. The crew then decided to intercept the first leg which had been missed. In doing so, the pilot missed the arrive circle of the next waypoint, which accounts for the first pilot, non-Loran-C navigator, related blunder. The pilot turned onto the proper bearing for the next leg but did not realize he had no navigation for that leg until he had accumlated a 1.0 nm CTE.

The sector search pattern shown in Figure 5.23 experienced one missed waypoint due to the signal interference, which caused the pilot to overshoot pattern 2, segment 1,2 by about 0.5 nm. The last two patterns of the sector search were not flown due to low fuel.

C. Depart and Resume Search

The depart and resume search function of the Loran-C navigator was

executed without any operational problems, demonstrating the ability of the navigator to provide precise navigation to a point which had been previously departed and resume search. This function operated equally well for both the creeping line and sector search patterns as indicated in Figure 5.22.

Figure 5.23 shows a situation where the depart, resume search function failed to operate properly on the creeping line pattern. The navigator provided guidance back to the leg where the aircraft departed from, but not to the same point. Upon arriving back at the proper leg, the navigator automatically sequenced a leg change as it was supposed to, however, it indicated that the aircraft was 3.0 nm left of the desired track when in reality it was not. A manual leg change by the copilot guided the aircraft to the next leg. Whether this malfunction was due to strong signal interference or a software problem has not been determined. Later attempts to depart and resume search were successful.

The depart and resume search maneuver was not executed during the sector search pattern in the interest of fuel.

D. Rho, Theta Waypoint Navigation

Figures 5.22 and 5.23 also illustrated the use of the Loran-C navigator to create and provide guidance to a rho, theta defined waypoint. In Figure 5.22, the copilot required approximately two minutes to create the rho, theta waypoints from waypoint intermediate, which he was navigating to. Once rendezvous was created, the copilot incorrectly executed a leg change from intermediate to rendezvous. This was immediately recognized and a leg change from present position to rendezvous was inserted. The total operation accounted for about three minutes.

Figure 5.23 shows a programming time that was much shorter. The same copilot as in Figure 5.22 created the rho, theta waypoint rendezvous and provide guidance from present position in approximately 40 seconds.

E. Parallel Offset Guidance

The parallel offset function provided guidance 3.0 nm right of track, Figure 5.22, and 3.0 nm left of track, Figure 5.23, with only one operational problem encountered. However, the test shown on Figure 5.23 was affected by apparent signal interference, in that the CTD on the Loran-C navigator and the CDI fluctuated, describing a wavy course. From the time the aircraft arrived at rendezvous waypoint to the time the aircraft was stabilized on the offset required about 4.3 minutes.

The test shown on Figure 5.22 required about 3.9 minutes from the time the aircraft arrived at rendezvous to when it was stabilized on the offset course. This also included a copilot operational error in programming the navigator for a 0.3 nm right offset instead of a 3.0 nm right offset.

On each parallel offset test, guidance was provided to the bisector angle of the next leg in the auto waypoint sequence mode.

F. <u>Direct-To Waypoint Navigation</u>

No operational problems were encountered during the use of direct-to navigation from the parallel offset to Cape May. To execute this maneuver the copilot had to execute a manual leg change from present position to Cape May and then clear the parallel offset function or vise versa. Considering these operations and translating them into an ATC environment an undesirable aspect arises. Suppose the aircraft is offset from his downwind leg and then is advised to proceed direct-to the FAF. It would be highly undesirable for the possibility to exist that the aircraft could remain on an offset to the FAF from present position.

As can be seen in Table 5.30, of the ten pilot-related operational problems, eight were identified as missed waypoints. Of these eight, seven can be attributed to strong Loran-C signal interference affecting Loran-C guidance. The remaining two pilot blunders were programming related, one affected probability of detection and the other affected parallel offset guidance. There were three Loran-C related operational problems, two of which were WARN lights. One of the WARN lights caused a waypoint to be missed; the other was of no consequence. The remaining Loran-C operational problem involved the failure of the depart and resume search function to provide correct guidance to the resume search point.

Table 5.30 Summary Of SAR Operational Problems

Pattern	Pilot	Loran-C Navigator	Comments
Creeping Line	7 (6 missed WP's)	1 WARN	One program error. Six WP's missed due to signal interference
Sector Search	2 Missed WP's	1 WARN	One WP missed due to signal interference
Depart/Resume Search	None	1	Undetermined cause
Rho, Theta	None	None	
Parallel Offset	1 Program Error	None	Program error
Direct-To	None	None	
Summary	10	3	Eight missed WP's. Two Program errors. Two WARN lights. One problem undetermined.

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5.4 VOR/DME COVERAGE DATA

One of the test program objectives of the FAA was to acquire preliminary data on VOR/DME signal coverage at low altitudes in the Northeast Corridor. For this reason, the subject pilot was asked to tune in the VORs specified for the NEC routes (see Tables B.1 and B.2) and monitor dropouts while navigating with the Loran-C navigator. The test observer assisted in monitoring VOR and DME dropouts and recorded both those observed by the pilot and his own observations. This manually recorded data was collected during five low altitude (500 feet to 2000 feet AGL) flights in the NEC.

Table 5.31 presents a summary of the data collected. As shown in the table, there were very few areas along the NEC that VOR/DME data was not adequate even at the low altitudes flown. For the five flights where data was logged, two flights did not experience a single dropout (numbers 1 and 3 in Table 5.31). During the remaining three flights, one station (PVD) would not lock-on while northbound at 800-1000' AGL enroute to Boston (number 3). One station lost lock while on final approach (flight 5, Table 5.31). In addition, two stations lost lock temporarily (SBJ and ABE on flight number 4 in Table 5.30).

Table 5.31 VOR/DME Dropout Data

Altitudes	Route	Stations Monitored	Problems
1. 500'-1000' AGL	NEC Southbound BOS to DCA	BOS, PVD, MAD, RVH, JFL, COL, SBL, ARD, MXE, LRP, EMI, DCA	No Dropouts For Entire Route
2. 1500' AGL to JFK 800'-1000' JFK to BOS	NEC Northbound Jonns Waypoint To BOS MAWP	RBV, COL, JFK, RVH, MAD, PVD, BOS	Could Not Lock-on PVD
3. 600'-1500' AGL	RCA Spurs	OOD, ARD, WRI, RBV	No Dropouts
4. 600'-2000' AGL	Allentown	COL, SBJ, ABE,	SBJ Lost For 45 sec. ABE Lost 1 1/2 min.
5. 500' AGl	Sikorsky Approach to LGA	DPK	Lost Lock on Final

The lack of a significant number of signal dropouts could be attributed to two reasons. First, the stations tuned were those specified on the FAA approved route. These stations may have been flight checked for adequate signal coverage even at the low altitudes tested prior to approval of the NEC routes. Second, the TACAN receiver used to collect this data may have been inherently more accurate than

the typical VOR/DME set. There may have been other reasons for the excellent signal strength and coverage, but they are unknown at this time. From the data taken, it can be concluded that no significant station dropouts were encountered.

6.0 SUMMARY OF RESULTS

This section presents a compilation of the significant results discussed in, and derived from, the analysis presented in Section 5.0. For ease of correlation with the more detailed discussion presented in Section 5.0, the major sub-sections of this section correspond directly to those of the previous section.

6.1 NORTHEAST CORRIDOR OPERATIONAL RESULTS

- The enroute NEC tests performed showed that the ±2.0 nm boundary established by the FAA for these routes was never exceeded by either test helicopter. In fact, the statistical data indicated that ±1.0 nm was never exceeded on a two-sigma, 95% probability basis.

- Based on ARTS III and IA tracking data (with known and quantified accuracies) the following overall statistical results were obtained for the four error quantities:

Error Quantity	Enroute $\pm 2\sigma$ Error Summary
Total System Crosstrack	0.60 nm
Flight Technical Error	0.19 nm
Airborne System Error	0.58 nm
Alongtrack Error	0.69 nm

- A total of 58 events indicative of potential operational problems were encountered during the Loran-C evaluation. Twenty seven events were pilot/copilot procedures, 22 events were Loran-C navigator hardware or software and nine events were in the ATC area.

- The analysis of ARTS III tracking accuracy for PHL and EWR facilities, compared to NAFEC's precision EAIR, showed that ARTS III errors varied from 0.1 nm within 10 nm of the antenna to as much as 0.65 nm at distances greater than 50 nm from the antenna.

- Analysis of transition, or spur, route segment data for Sikorsky, Mack Truck, RCA and New York Airways showed errors comparable to enroute NEC results.

- The spur route segment data also showed significant variations depending on which ARTS III or IA data was being used to determine TSCT errors.

- All spur route data fell within the following error values:

Error Quantity	Maximum $\pm 2\sigma$ Spur Route Data
Total System Crosstrack	±0.70 nm
Flight Technical Error	±0.25 nm
Airborne System Error	±0.70 nm

6.2 NAFEC SYSTEM ACCURACY RESULTS

- In the non-updated mode, the enroute NAFEC data showed production AN/ARN-133 accuracy to be within ±0.60 nm. This resulting accuracy was consistent for both the new 9960 chain and the old 9930 chain. No difference in enroute accuracy was measured for the two helicoptors tested (HH52 and HH3).

- The production Loran-C navigator accuracy enroute was ±0.54 nm compared to a value of ±0.56 nm obtained during the prototype evaluation at NAFEC.

- The effect of updating the Loran-C navigator was to reduce the bias error measured in the NAFEC area during the enroute flights.

- In the terminal area, the production Loran-C navigator stayed well within the ±1.5 nm protected airspace limit. The measured TSCT was ±0.32 nm for the HH3 and ±0.46 nm for the HH52.

- The non-precision approach accuracy of the production navigator was approximately one-third of a nautical mile in the non-updated mode. At NAFEC this error was consistently left of the runway centerline for runway 04.

- Overall comparison of measured AN/ARN-133 total system accuracy (at NAFEC) compared to AC 90-45A requirements was as follows:

	Crosstrack		Alongtrack	
	AC 90-45A	Measured	AC 90-45A	Measured
Enroute	2.5 nm	0.6 nm	1.5 nm	0.2 nm
Terminal	1.5 nm	0.5 nm	1.1 nm	0.6 nm
Approach	0.6 nm	0.5 nm	0.3 nm	0.5 nm

- Qualitative non-precision approach testing at Boston, Massachusetts and Frederick, Maryland confirmed the accuracy measured at NAFEC.

- A repeatable sinusoidal Loran-C bias error was measured by testing the navigator on final approach to all six runway headings at NAFEC. This error varied between the limits of ±0.4 nm and passed through zero at approximately 90° and 270° from true north. This bias behavior was documented in the NAFEC area for both the production and prototype navigators. No quantifiable change in this bias behavior occurred between the 9930 and 9960 chain data.

6.3 OFFSHORE RESULTS

- The AN/ARN-133 navigator accuracy typically remained within ±0.5 nm out to the 200 nm limit tested on the deep probes overwater. However, one flight experienced a Loran-C cycle jump within 40 nm of the coastline which caused a 1.0 nm crosstrack navigation error.

- No operational ATC problems were encountered during the Deep Probe testing.

- No significant coastline signal anomalies were measured either by the EAIR tracking radar or by the airborne Loran-C navigator.

- The Loran-C navigator reduced the pilot and copilot workload during ship/helo rendezvous testing.

- Aggregate Loran-C 2 d_{rms} position error was approximately 1700 feet for the three oil rig locations tested, using Loran-C Chain 9930 in the Gulf of Mexico.

- Automated Search and Rescue performance with the Loran-C navigator was acceptable. Testing included:

    1) Creeping Line Patterns
    2) Sector Search Patterns
    3) Depart and Resume Search
    4) Establishing a Rho/Theta Waypoint
    5) Parallel Offset Guidance
    6) "Direct-To" Waypoint Navigation

7.0 CONCLUSIONS

The major conclusions from the operational flight test evaluation of the production Loran-C navigator are summarized in this section. These conclusions are, by intent, qualitative in nature. The quantitative results from which these conclusions were reached are summarized in Section 6.0 and discussed in depth in Section 5.0. These conclusions are organized in the order of the general program objectives stated in Section 1.1. Following the statement of a conclusion regarding each general objective are summary conclusions for the more detailed objectives evaluated.

- Northeast Corridor Operational Testing

  The production Loran-C navigator was determined to be acceptable in the operational environment of the Northeast Corridor for both enroute and point-in-space approaches.

  1) The navigation accuracy and functional performance of the production navigator was acceptable from both the pilot's viewpoint and an ATC viewpoint.

  2) Operation of the Loran-C navigator in a primarily VOR/DME ATC environment in the NEC did not cause any significant operational problems.

  3) Pilot workload and ATC interfaces were acceptable on the transition routes to and from the Northeast Corridor utilizing the Sikorsky, Mack Truck, RCA and New York Airways routes.

  4) Additional non-precision Loran-C approach data was acceptable in the Boston, Massachusetts and Frederick, Maryland areas.

  5) Loran-C performed acceptably as an approach aid to point-in-space approaches flown at Boston, Massachusetts and Washington, D.C. as well as during the spur route PISA testing. This acceptable performance included approaches to unaided helipads.

  6) No significant VOR/DME signal dropouts were observed during the low altitude Northeast Corridor testing.

- NAFEC System Accuracy Testing

  The production Loran-C navigator satisfied AC 90-45A accuracy requirements for enroute and terminal area in both alongtrack and crosstrack directions. For non-precision approaches, the navigator satisfied the crosstrack accuracy requirements but did not satisfy the alongtrack accuracy requirement.

  1) Additional Loran-C navigator accuracy data was

compiled for AC 90-45A compliance using the HH3 and HH52 helicopters

2) The production Loran-C navigator's telemetry position down link function worked acceptably as an aircraft surveillance aid.

- Offshore Testing

The production Loran-C navigator performed acceptably during all phases of offshore testing.

1) Operation of the Loran-C navigator was successfully demonstrated during long range (100-200 nm) overwater missions.

2) No Loran-C signal anomaly was measured or observed during the overland/overwater transition testing.

3) The Loran-C navigator reduced workload and improved accuracy during ship/helo rendezvous tests and offshore oil rig tests.

4) The production Loran-C navigator verified the prototype navigator's accuracy and repeatability during SAR and surveillance testing.

REFERENCES

1. Adams, R.J., "An Operational Evaluation Of Flight Technical Error", Systems Control, Inc. (Vt), Champlain Technology Industries Division for the Federal Aviation Administration Systems Research and Development Service, FAA-RD-76-33, November 1976.

2. Hughes, M. and Adams, R.J., "An Operational Flight Test Evaluation Of A Loran-C Navigator", Systems Control, Inc. (Vt), Champlain Technology Industries Division, for the the United States Coast Guard Office of Research and Development, CG-D-9-77, March 1977.

3. Anonymous, "Operator's Manual TDL-424 (AN/ARN-133V2) Loran Navigator", Teledyne Systems Company, 1 January 1978.

APPENDIX A

EQUIPMENT SUMMARY

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APPENDIX A

A.1 EQUIPMENT SUMMARY

The AN/ARN-133 Loran-C Navigator tested was the production version of the TDL-424 prototype navigator previously evaluated (Reference 2). The navigator is a self-contained Loran receiver and navigation computer requiring only an antenna and a TDL-414 antenna coupler unit. The antenna coupler provides impedance matching and bandpass amplification for received Loran signals, notch filters to remove interfering frequencies and a tunable voltmeter to adjust the notches. The navigator processes Loran signals, computes and displays all information selectable on the display switch, as well as other system test and evaluation data. Steering signals are sent to the aircraft's course deviation indicator to provide steering control to selected waypoints. Selected data are sent, either manually or automatically, to the aircraft communications system via an ASC II data link subsystem for transmittal to other air, sea or ground units. The AN/ARN-133 can also interface with an optional incoming data link to provide remote waypoint entry and other features, when desired. Range-to-go signals are provided for remote displays. Discrete signals are also provided for arrive and five-miles-to-go lights on optional indicators.

The AN/ARN-133 airborne Loran-C navigator provides comprehensive navigational data as follows:

- Present position in lat/lon or time differences
- Great circle range from present position to the selected "To" waypoint
- Bearing to the selected "To" waypoint
- Nine waypoint storage capability
- Desired track using two waypoints
- Actual track angle
- Desired track angle
- Track angle error
- Ground speed
- Cross track distance error
- Steering outputs available for Loran deviation indicator, course deviation indicator, and autopilot
- Time-to-go to selected waypoint

Additional features include:

- Automatic Loran secondary station selection, waypoint and leg change
- Automated search pattern calculations
- Master independent operation
- RHO/THETA steering to an ad hoc waypoint
- Position updating
- Data link
- Magnetic variation entry
- Moving waypoint navigation

All operator controls and indicators are located on the AN/ARN-133 front panel shown in Figure **A.1** Detailed explanations of switch, indicator, and display functions are contained in Reference 3. Use of these functions in actual operating procedures is described in Sections IV, V and VI of the reference.

A.1.1 The AN/ARN-133 Navigator System

The TDL-424 is comprised of a Loran receiver, a high-speed digital computer and a unique program intelligence that makes the machine a navigation system. How time difference mapping is converted into lat/lon mapping is shown in Figure A.2, which is a simplified functional diagram of the software being used.

Received Loran signals are processed under software control to produce the two basic time differences, TDA and TDB. These represent present position time differences. The coordinate converter position of the program performs calculations required to convert these into lat/lons. The coordinate converter performs the same function for waypoint TDs input from the panel.

The lat/lons can be corrected for propagation anomalies by position updating and displayed as required. This procedure is normally used during system initialization by entering a known value of aircraft lat/lon position; for example, the ramp location or the end of the runway. The position update procedure is accomplished by entering the known position in either lat/lon or time difference coordinates.

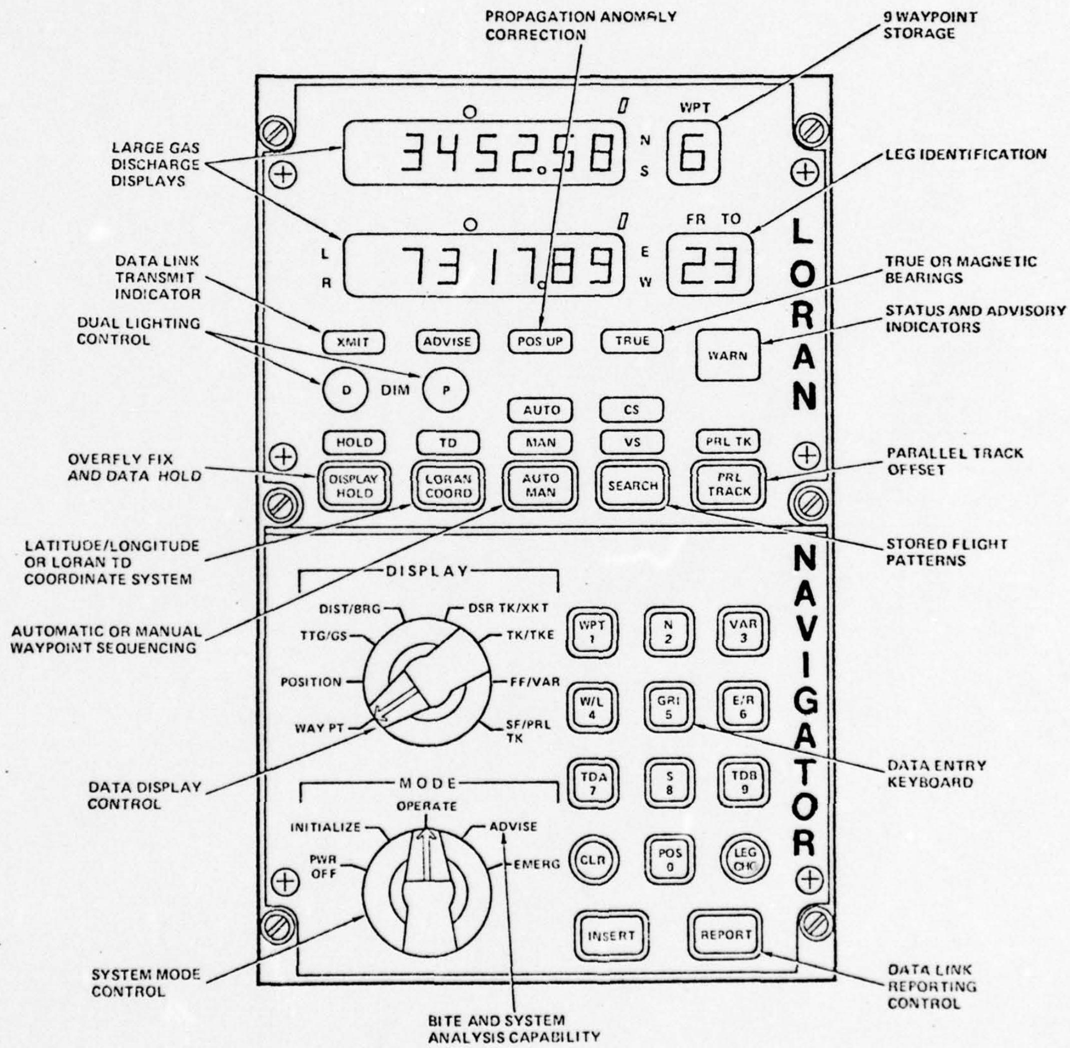

Figure A.1 AN/ARN-133 Front Panel Display

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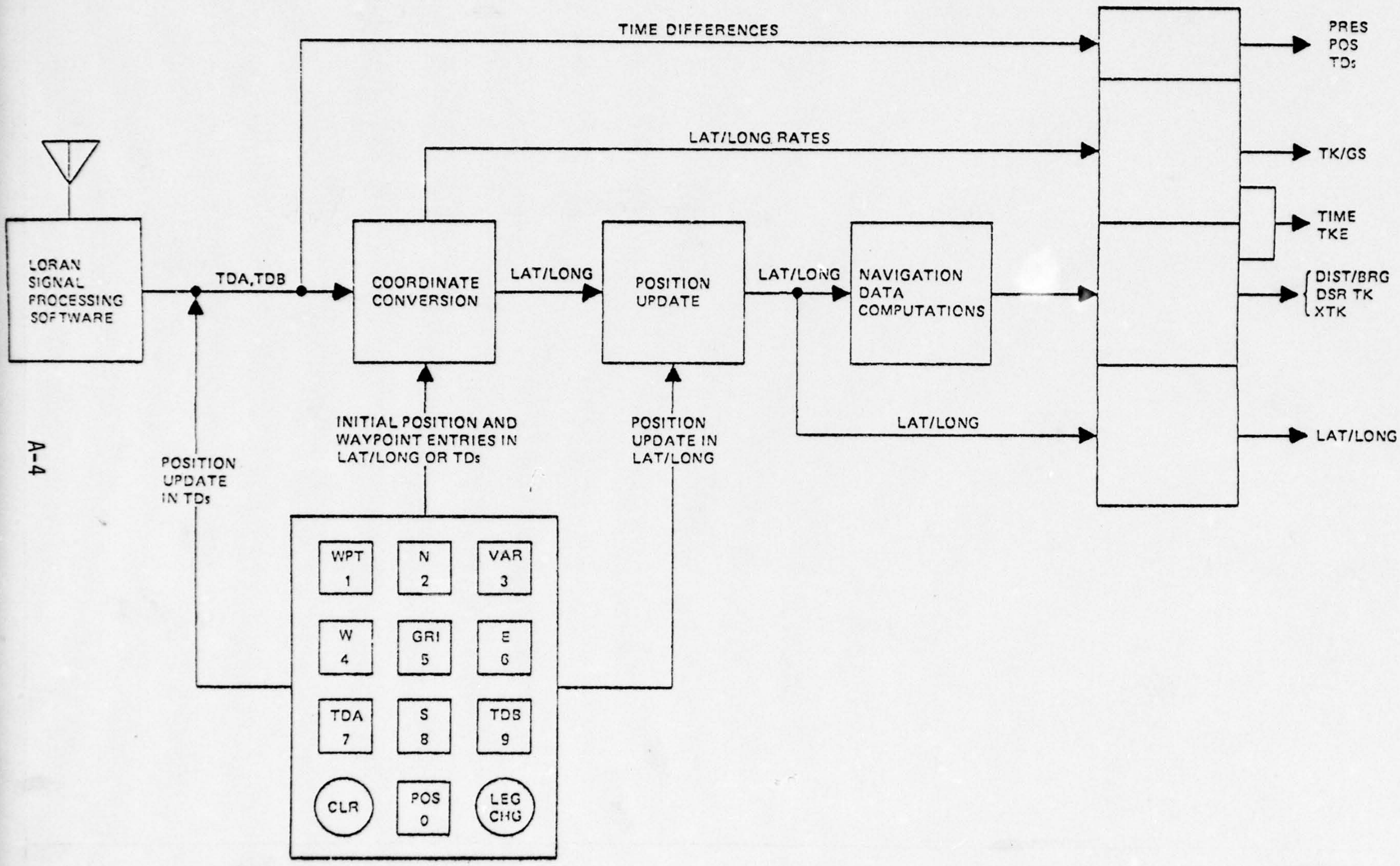

Figure A.2 AN/ARN-133 Functional Block Diagram

It should be noted that the update corrections are automatically cancelled when the secondary stations in use are changed either automatically or manually. It should also be noted that the net effect of the update is to remove any Loran-C bias errors due to station geometry. These bias errors are not consistent when changing secondaries. Consequently, the navigator can no longer apply the correction factor.

Other navigation data is obtained by specific software routines, converting the continuing stream of lat/lon information into data the operator may select for display. All computations involving position and steering data are made in the lat/lon geodetic system. Conversion to and from both lat/lon and time differences is necessary for display and input purposes.

Time difference to lat/lon conversion for waypoints is done by an iterative procedure that stops when the TD errors are both less than 10 nanoseconds. The waypoint TDs entered into the system via the front panel are erased from memory as soon as the latitude and longitude are computed. The TDs will be reconstructed from the latitude and longitude whenever the operator requests the TDs of the waypoint. As a result, the displayed TDs may differ from the originally inserted TDs by as much as 10 nanoseconds each.

Range and bearing, cross track error, desired track angle, and time-to-go are computed four times per second. Output to the steering indicators is once per second; track and ground speed are also once per second. The range calculations switch from great circle to flat earth at ranges smaller than about 10 nautical miles.

Figure A.3 is presented to illustrate the terms referenced in Figure A.2. The definitions of the terms in Figure A.3 are as follows:

VAR - Magnetic Variation -- Angle between true north and magnetic north. This value changes as a function of aircraft position, and is manually updated during flight. (Note: When zero magnetic variation is in the system (True indicator lighted), bearing and track angles become referenced to true north).

DIST - Distance -- Great circle range from present position to "To" waypoint.

BRG - Bearing -- Angle between true north and a line from present position to "To" waypoint.

TK - Track angle -- Angle between true (or magnetic) north and actual ground track.

GS - Average Ground Speed -- Rate of aircraft travel, computed by differentiating lat/lon positions once per second.

DSR TK - Desired Track Angle -- Angle between true or magnetic north and desired track.

TKE - Track Angle Error -- Angle between actual track and desired track.

XTK - Cross Track Distance (error) -- Left or right, of present position from desired track, measured on a line perpendicular to desired track.

TIME - Estimated time to go to selected "To" waypoint.

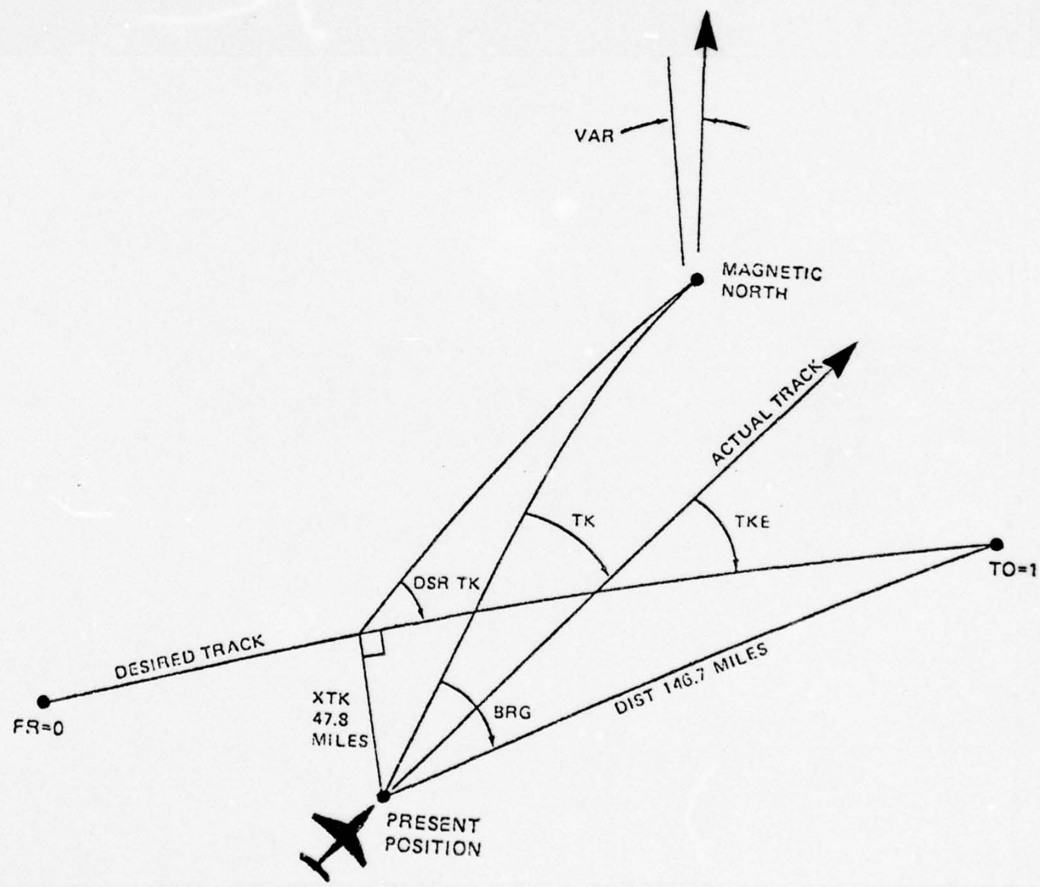

Figure A.3 The AN/ARN-133 Navigation Coordinate System

It should be noted that three displayed functions -- track angle, track angle error, and time-to-go to selected "To" waypoint -- are functions of velocity that become unstable when the velocity is small. Below 10 knots the display of these functions is inhibited. Also, navigating beyond the latitude range of 80°S to 80°N can cause numerical overflows in the navigation computations due to meridian convergence.

A.1.2 AN/ARN-133 Navigation Techniques

A comprehensive list of AN/ARN-133 navigation techniques is contained in the operator's manual provided by Teledyne Systems Company (Reference 3). This section summarizes a few of the operationally important features and highlights potential uses and/or problems where applicable.

A. WAYPOINTS

The use of waypoints is the heart of navigating with the AN/ARN-133. A waypoint is defined as any position to be used in navigating or any point for which navigational data is desired. The program is designed so that navigation and steering are supplied for any two points appearing in the FR and TO windows. The system always navigates with reference to two points -- a "From" point and a "To" point. Either a line between two waypoints (FR and TO), or a line from aircraft present position (waypoint 0) to another waypoint may be used. Selecting two waypoints (FR and TO) defines a great circle course connecting the two positions entered. Selecting waypoint 0 and another waypoint defines a great circle course from the present "Insert" position to the selected "To" waypoint. These procedures, in effect, create a new leg with the aircraft present position as the new "From" waypoint.

The various waypoints on a mission are entered via the keyboard. Up to nine positions may be entered (1-9) in either lat/lon or TDs (or a mix) and a "table" of points is then stored in the computer memory that can later be called up for reference or use in navigating. The way these waypoints are called up in flight determines the kind of steering supplied.

If a "From" and "To" leg is called up by entering the numbers of the two desired waypoints, steering and navigational data are obtained with respect to the course defined by those two positions. If an "0" and "To" waypoint are called up, steering and navigational data from present position to the selected "To" position will be provided at the time the INSERT key is pressed.

The AN/ARN-133 provides the alternatives of automatic or manual waypoint selection. In AUTO mode, the program sequences legs automatically, selecting the next leg in numerical sequence as the aircraft arrives at a waypoint destination. In the MANUAL mode, the operator must make the selection of the next leg. Each leg must be called up when needed, and navigation/steering information will be with respect to that leg until a manual "LEG CHANGE" and "INSERT" operation is performed. This is true even if the aircraft has arrived at or passed a waypoint.

Loran time difference navigation has been demonstrated to be a system of navigation with a high degree of repeatability. Time differences are directly relatable to position for a specified Loran chain, and it is possible to return to a position based on a time difference fix without the use of charts or other data. The AN/ARN-133 makes practical use of this principle by allowing waypoints to be entered in time differences as well as lat/lon.

B. INTERWAYPOINT RANGE AND BEARING

This pilot procedure may be required while navigating on the desired course. However, the pilot may be requested to report the aircraft's present position with respect to a waypoint further along in the flight plan or a waypoint on a nearby route not currently stored in the navigator. Even more frequently, a position report is requested with respect to a nearby VOR station whose position the controller is familiar with. The capability to obtain range and bearing from present position to any waypoint or from any waypoint to any other waypoint is provided by this function. The system calculates distance and bearing from the designated "From" waypoint to the designated "To" waypoint and displays this data for 10 seconds. This procedure provides range and bearing information for orientation purposes without steering.

C. PARALLEL TRACK STEERING

The parallel track steering feature is designed for a special mission, such as airways offset track flying or search and rescue missions. Parallel track steering provides the ability to fly along a course parallel to a given course at a selectable distance from it. The offset distance can vary from .1 to 99.9 nautical miles. A series of such offset legs may be flown corresponding to as many "From" and "To" legs as are entered in the system (nine maximum). Also, the offset distance can be changed in mid-leg.

The AN/ARN-133 program provides this capability by projecting an artificial destination based on the nominal course coordinates and the offset distance entered. As indicated in Figure A.4, in order for the program to derive the artificial destination 3', it needs the coordinates of waypoints 2, 3 and 4 plus the offset distance, D.

Once the offset has been entered, all steering and other nav data are with reference to the artificial destination. The original waypoint-defined course is not lost, however; it is held in memory until the parallel track steering command is cancelled by entering zero offset distance.

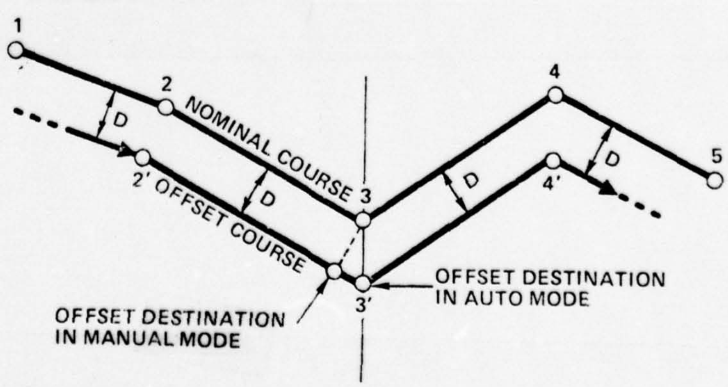

Figure A.4 Loran-C Parallel Track Illustration

A subtle system characteristic develops when flying in the parallel track steering mode. This characteristic is dependent upon whether auto or manual waypoint selection is chosen. In the auto mode, the AN/ARN-133 performs the necessary trigonometry to determine the angle bisector between the inbound and outbound legs of the active "To" waypoint. The automatic leg switching then occurs with respect to the waypoint displaced along the angle bisector a distance equal to the parallel track offset.

In the manual waypoint selection mode of operation, the AN/ARN-133 does not have any information stored regarding the outbound course from the active "To" waypoint. Consequently, the software is set up to indicate arrival at the waypoint based on a projection of the waypoint orthogonally a distance equal to the parallel track offset.

Previous flight testing of systems using each of these techniques (bisector vs orthogonal projection) has shown that operational ATC problems can occur (turn overshoots or corner cutting) with either technique depending on the magnitude of the turn, the magnitude of the offset and the relationship of the turn direction to the offset direction (inside or outside of the turn). This testing has also shown that pilot/crew procedures can be developed which compensate for the errors induced for these special geometries. However, switching techniques as a function of manual vs auto mode forces the pilot/crew to remember two different sets of special cases and applicable procedures. This may be confusing to the users especially in high workload areas of flight, such as during a SID or STAR.

D. TELEMETRY DATA LINK REPORTING (FLIGHT FOLLOWING)

The data link reporting function is called flight following (FF) because it enables the aircraft to be "followed," i.e., tracked by other aircraft, ships, or ground stations. The telemetry report generated within the AN/ARN-133 and transmitted via the aircraft communications system contains the following:

- <u>Message</u> - This is either aircraft present position or whatever is appearing in the upper and lower displays, depending on report mode and report code selected.

- <u>Reference data</u> - This includes aircraft identification number, Loran signal status, and report code, which sets up the type of reporting to be done.

The pilot/crew has flexibility within three data link reporting modes: emergency, manual, and automatic. If no report code is entered, automatic reporting (code 0) of aircraft present position occurs. If a report code of 0 and any single digit from 1-6 is entered, automatic reporting of the DISPLAY switch setting occurs and the message is tagged with that identifying digit. If you enter only the single digit from 1-6 without a 0, you'll get manual reporting of what's displayed, under control of the REPORT switch.

E. RHO/THETA STEERING

The rho/theta steering function calculates the latitude and longitude of a waypoint that lies at a given distance (rho) and bearing (theta) from a given waypoint or present position. This function can be used in two ways : 1) The computer can calculate lat/lon of the projected point and store it in a specified waypoint for future use; 2) The computer can calculate the lat/lon of the projected point, store it, and automatically initiate a leg change to provide steering to that point. Figure A.5 illustrates this function. The AN/ARN-133 will not accept entries of rho distances over 250 nm.

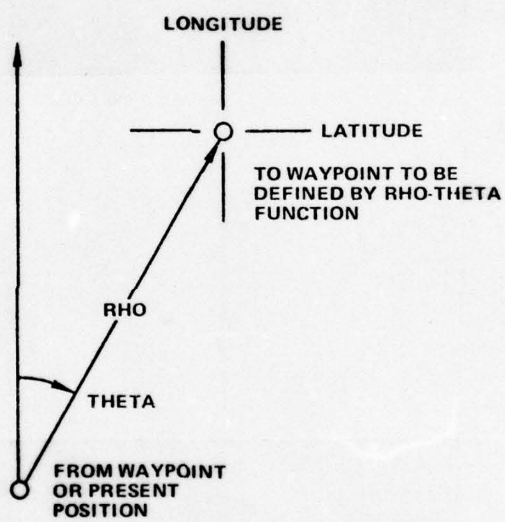

Figure A.5 Rho/Theta Steering Geometry

The computer calculates the lat/lon of the projected point and stores it in the selected "To" waypoint. To obtain steering "To" this point, the "From" waypoint must be designated as waypoint "0" (present position). Any other single digit designation for the "From" waypoint will cause the computer to calculate the lat/lon of the projected point and store it in a specified waypoint for future use.

F. REMOTELY SUPPLIED (data linked) NAVIGATION

The AN/ARN-133 provides navigation and steering to waypoints remotely supplied to the unit. By means of the TDL-471D Airborne Data Link Decoder, data link messages from any remote source — other aircraft, ships or shore stations — can be fed into a selected waypoint in the AN/ARN-133 to provide remotely generated destination coordinates.

The source from which such data link messages are to be received can be selected by means of the ID select switches on the TDL-471D. The mode of data transfer from TDL-471D to navigator can be either manual or automatic, and the location into which this remote data will be stored is selectable using the standard waypoint call up procedure.

G. MASTER INDEPENDENCE

The AN/ARN-133 is designed to operate without the master Loran signal when at least three secondaries are receivable. This feature covers the conditions where the master signal is not receivable during search or where it is lost after navigation has begun. In such cases, the program designates a secondary as master and new LOP's (Lines of Position) are calculated. Whenever the master signal becomes receivable again, it is picked up and treated as though it were another secondary. This feature operates automatically without operator action, but can be overriden (master independence override).

The ADVISE indicator lights when master independence is enabled. When the MODE switch is set to ADVISE and the DISPLAY switch to DIST/BRG, the right-most digit in the lower display tells which secondary is designated as the master. When this digit is 0, the system has the real master and is operating normally; when this digit is 1, 2, 3 or 4, it identifies which secondary is being used as the master. With the DISPLAY switch at DSR TK/XTK, a "1" in the "No Master" digit of the upper display (middle digit) indicates the system does not have a master. This may also indicate master independence, but not decisively.

Whenever master independence is operative, the position update function (POS UPD) is nullified. Since a secondary signal is designated as master, a new frame of reference of hyperbolic TD lines is established, invalidating the position update, which is based on the real master-referenced system. Master independence also disables the automatic secondary change advise function.

A.1.3 AN/ARN-133 Display Interface

Navigational data derived from the Loran navigator, which is continuously displayed to the pilot, includes cross track deviation error (CDI) and To/From flag switch-over at waypoint passage. In the flight test installation the cross track deviation was displayed on the Navigation Flight Director Indicator (NFDI, Figure A.6) which was located in the center of the pilot's instrument panel.

There were two CDIs available in the cockpit during the flight test program. The primary instrument used by the pilot during the testing was the NFDI. The specific equipment shown was on the HH52 aircraft. However, the HH3 installation displayed crosstrack deviation and an integral on/off indicator. The NFDI has 4 dots on either side of the center circle (bull's-eye). Consequently, the ±0.5 nm sensitivity position gave the pilot the CDI needle deflection of ±0.1 nm per dot.

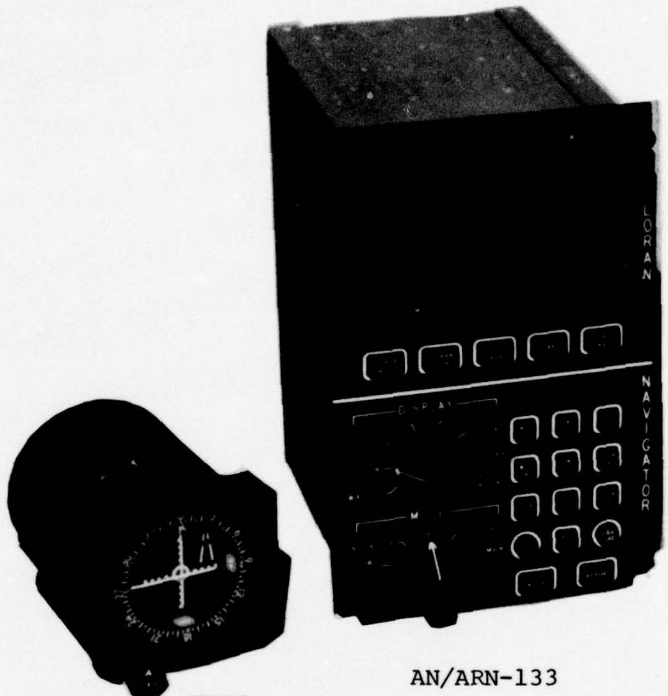

Figure A.6 TDL-AN/ARN-133 and NDFI Equipment Installed in USCG HH52 Aircraft

A.1.4 Loran-C Chains Utilized

Several Loran-C chains were utilized during the airborne evaluation of the AN/ARN-133 navigator. This was due to the fact that the tests were performed both in the Gulf of Mexico and on the East coast of the U.S. In addition, the period of performance of these tests coincided with the introduction of new chains for both of these test regions. Therefore, it is important to understand which configurations were used and to examine the Loran-C accuracy data for any effects due to chain geometry.

In the NAFEC and East Coast Offshore testing, two chains were used. The initial tests, performed between June and November of 1978, utilized the U.S. East Coast Chain (9930). In this configuration, the master station was located at Carolina Beach, North Carolina, the two secondaries were at Nantucket, Massachusetts and Dana, Indiana. Figure A.7 depicts the relative geometry of these Loran-C transmitters and indicates the location of the Northeast Corridor and NAFEC test areas with respect to each station. Figure A.7 also shows the coastline for references. The 9930 chain was used for navigation and data collection on the following tests:

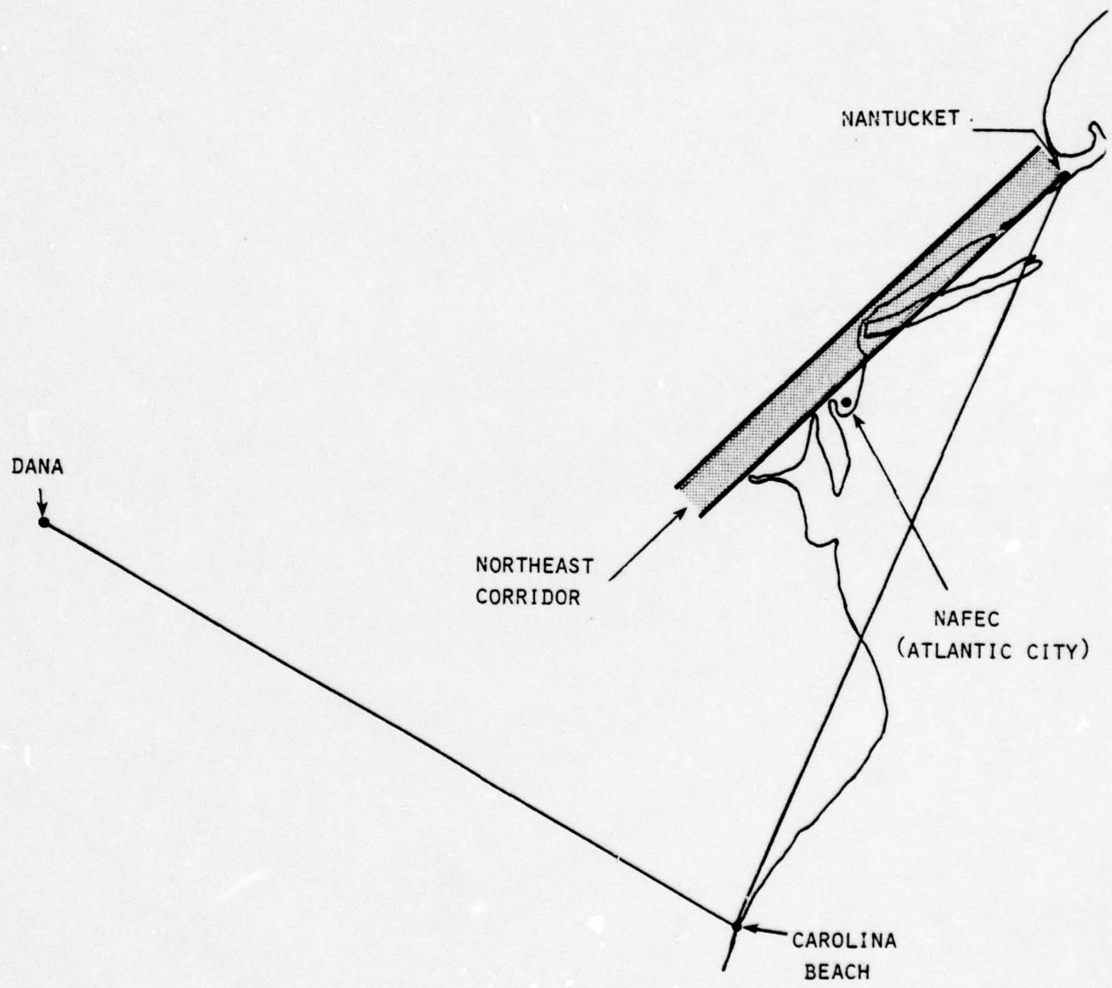

Figure A.7 U.S. East Coast Chain 9930
(to be discontinued 9/79)

1) Deep Probe Overwater in the HH3 (6/2/78)
2) SAR Testing in the HH52 (6/13/78 and 7/11/78)
3) NAFEC System Accuracy Tests (7/6-10/78)

The second chain utilized during the East Coast testing was the newly commissioned U.S. Northeast Coast Chain (9960). This chain came on-line during September 1978 and was used for testing from November 1978 through January 1979. The stations from this chain used during the Northeast Corridor, NAFEC and the remaining Offshore testing were the master located at Seneca, New York and secondaries at Carolina Beach, North Carolina; Nantucket, Massachusetts and Caribou, Maine. Figure A.8 illustrates the station geometry for the 9960 chain as well as the relative location of the Northeast Corridor test route, NAFEC and the coastline. This chain was used for the following test:

1) Northeast Corridor Northbound and Southbound Flights (11/1 through 11/15/78, 12/5 through 12/19/78 and 1/15 through 1/18/79)

2) NAFEC System Accuracy Tests (11/3-6-8/78 and 12/18/78)

3) Deep Probe Overwater in the HH3 (11/7/78)

4) Coastline Signal Anomaly Test in the HH52 (12/18/78 at dawn and 1/19/78 at dusk)

For the Gulf of Mexico Offshore testing, two chains were again utilized. The majority of the data was collected using the U.S. East Coast Chain (9930) since the U.S. Southeast Chain was not operational during the early test period. For this data, Carolina Beach was the master station with Jupiter, Florida and Dana, Indiana as the secondaries. Figure A.9 shows the geometry for the 9930 chain in the Gulf of Mexico. Data was collected on Loran-C accuracy and repeatability using this chain. The position references for this data were known oil rigs with surveyed lat/lon. The HH52 helicopter flew to single isolated rigs, multiple rigs and dense clusters and hovered over the destination rig while recording Loran-C position data. This data was collected from 20 July 1978 to 3 August 1978.

The second Gulf of Mexico chain used was the newly commissioned U.S. Southeast Coast Chain (7980). This chain was made operational during July 1978 although all secondaries were not available either in July or during the test period. Malone, Florida is the location of the master for the 7980 chain with Grangeville, Louisiana; Raymondville, Texas; Jupiter, Florida and Carolina Beach, North Carolina as secondaries. For the Ship/Helo rendezvous testing performed using this chain, Malone, Grangeville and Jupiter were used. Raymondville and Carolina Beach were not available. The Ship/Helo testing was performed on 10/19/78. Figure A.10 shows the station locations for these tests.

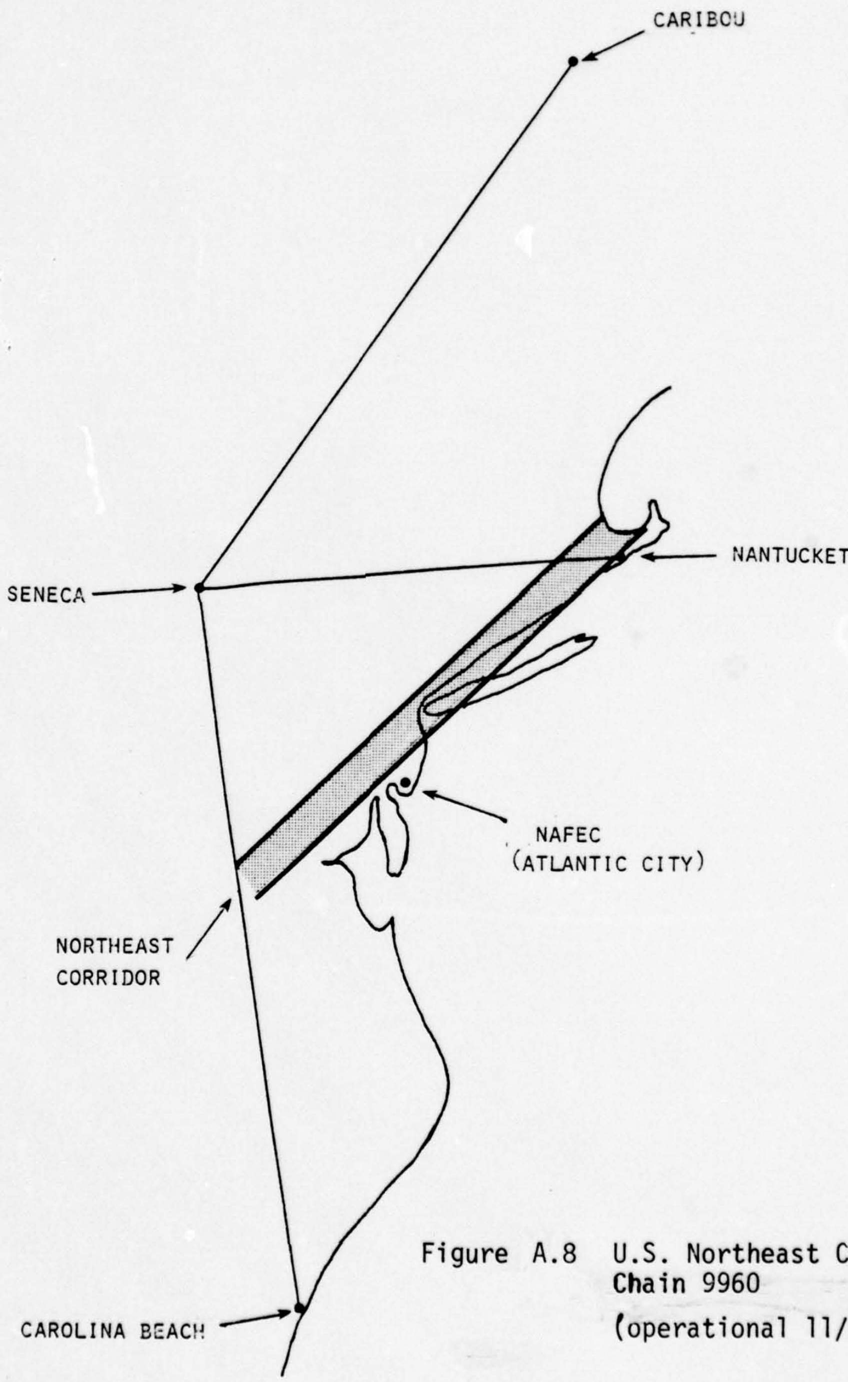

Figure A.8 U.S. Northeast Coast
Chain 9960
(operational 11/78)

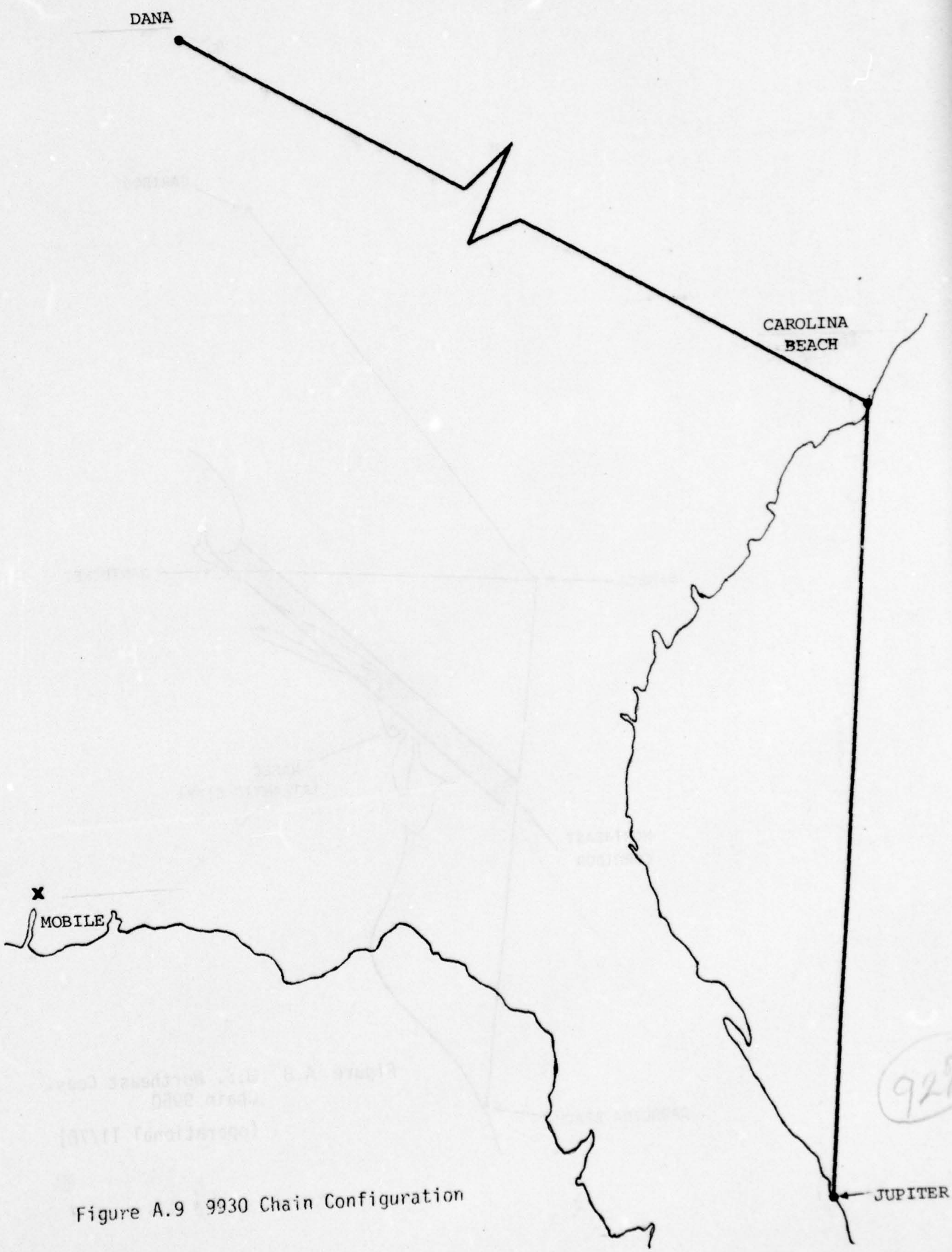

Figure A.9 9930 Chain Configuration

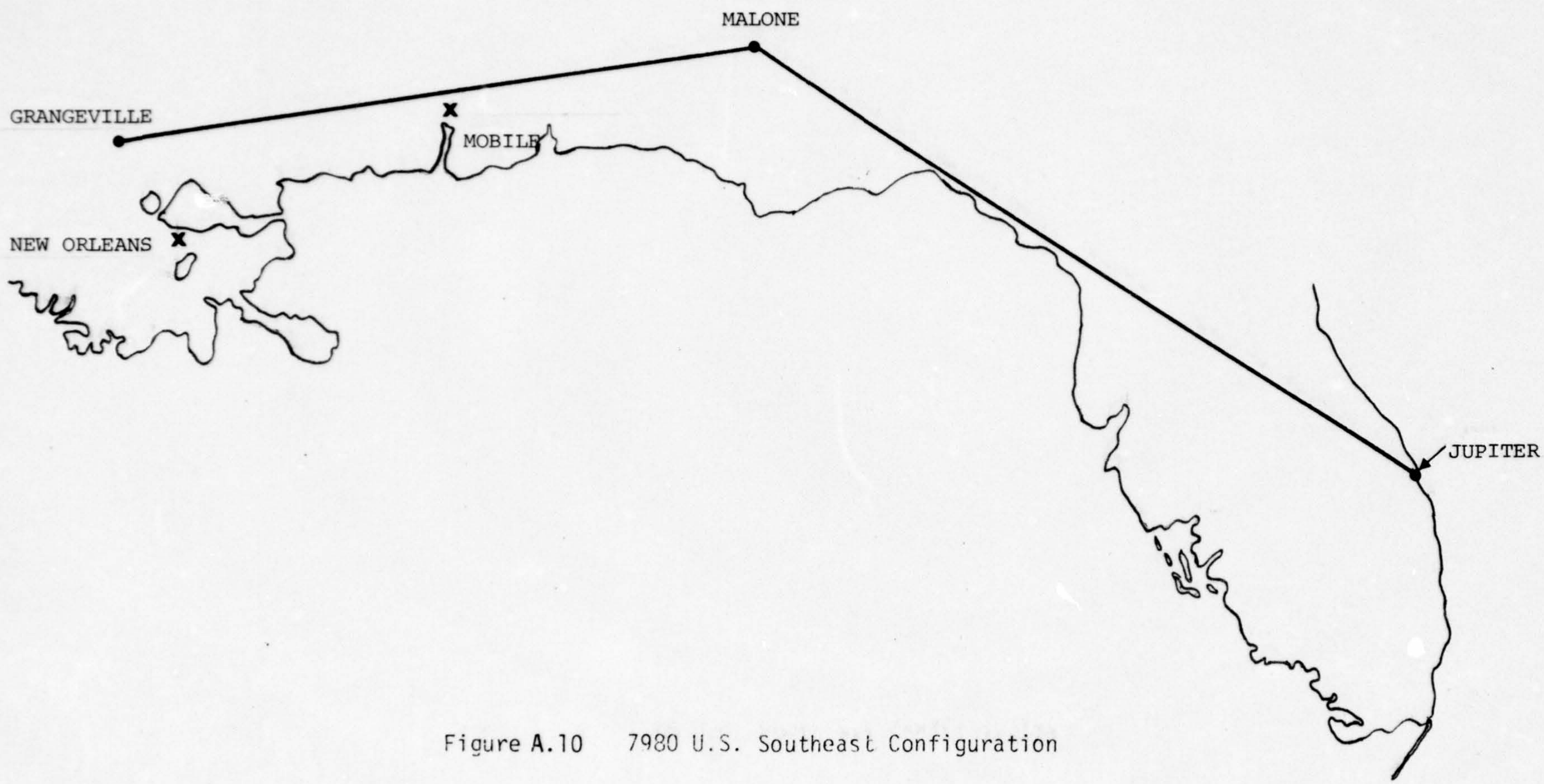

Figure A.10 7980 U.S. Southeast Configuration

A.1.5 Characteristics of the Test Aircraft

HH52 aircraft were provided for the AN/ARN-133 flight tests by the USCG Air Station located at Cape May, New Jersey and the Coast Guard Aviation Training Center at Mobile, Alabama. These are single engine helicopters which cruise at 80 knots. The HH52 aircraft is the primary search and rescue helicopter in the USCG fleet.

In addition to the HH52s an HH3 aircraft was provided by the USCG Air Station located at Otis, AFB on Cape Cod. The HH3 is an amphibious twin engine helicopter which is larger and faster than the HH52. Normal cruise speed is about 140 knots. The twin engine capability, as well as the longer range, made this aircraft more suitable for the deep probe overwater. Both test aircraft were flown in the Northeast Corridor and at NAFEC.

APPENDIX B

FLIGHT TEST PROFILES

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APPENDIX B

B.1 FLIGHT TEST PROFILES

The basic test program consisted of three categories of flight testing. These were defined as:

1) Northeast Corridor Operational Testing

   A) Enroute
   B) Transition (spur) Routes
   C) Final Approach Testing

2) NAFEC System Accuracy Testing

   A) Review of Prototype Navigator Data Base
   B) USCG Production Data
   C) Telemetry Tracking with Loran-C

3) Offshore Testing

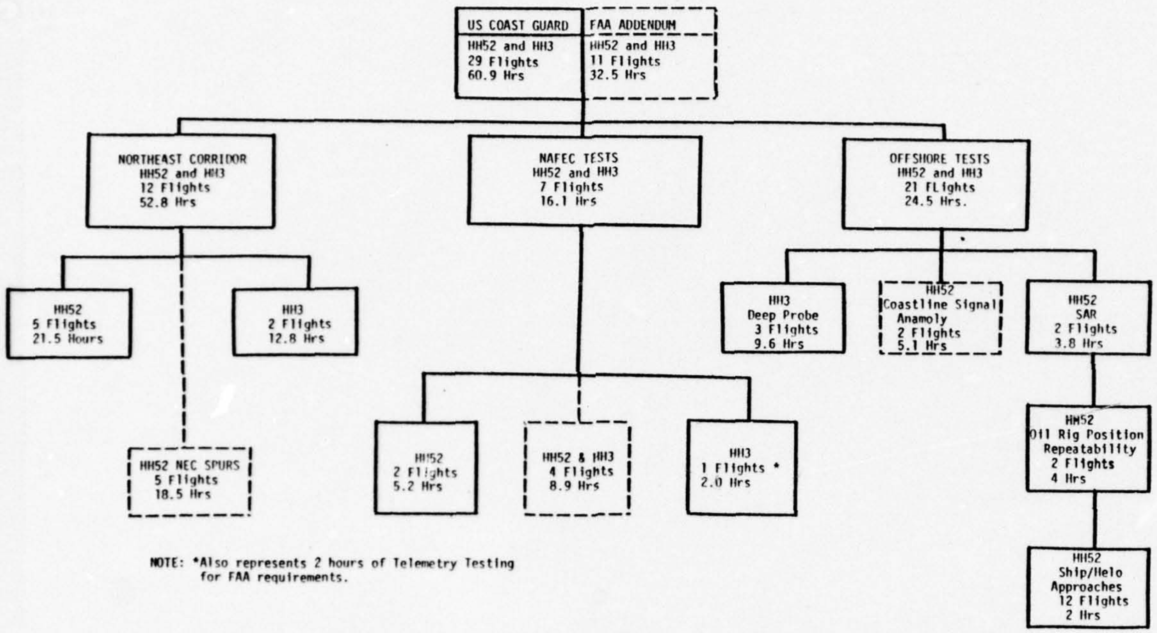
   A) Deep Probes Overwater
   B) Coastline Signal Anomalies
   C) Ship/Helo Rendezvous
   D) Oil Rig Tests
   E) Search and Rescue Tests

This section discusses the details for each of these categories including flight test routes, flight planning requirements, individual flight test matrices and summaries of number and type of segments flown (e.g., 19 enroute). In addition, total distance flown, Loran-C mode of operation, flight altitudes and specific waypoint location information was provided for each of the routes in all these categories.

Figure B.1 summarizes the overall AN/ARN-133 evaluation matrix. The variables of primary importance in this matrix were the aircraft used, the location of flights and the total flight hours. As shown in Figure B.1, the scope of the overall program was approximately 93 hours. Of this total, the HH3 tests compiled 13 hours in the Northeast Corridor and nearly 10 hours in the Deep Probe Overwater tests. In addition, the HH3 accounted for six of the 16 hours of NAS testing. The HH52 tests, therefore, comprise the remaining 40 hours of Northeast Corridor testing, 10 hours of NAS testing, and 15 hours of Offshore testing.

B.1.1 Northeast Corridor Test Routes

The Loran-C Flight Test Plan included approximately 53 hours of flight testing to demonstrate operation of the Loran-C navigator in the "Northeast Corridor" airspace environment. The demonstration process consisted of flying an experimental helicopter test route round-trip from Boston to Washington, D.C. to Boston using USCG helicopters equipped with a Teledyne AN/ARN-133 (TDL-424) Loran-C Navigator System. The purpose of these tests was to demonstrate the Loran-C Navigator System as an area navigation system suitable for operation on charted helicopter



NOTE: *Also represents 2 hours of Telemetry Testing for FAA requirements.

Figure B.1 Integrated FAA and USCG Flight Test Program Summary

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IFR routes and for integration in the operational environment of the National Airspace System. The functional performance of the Loran-C navigator in helicopter operations was evaluated in the high density ATC environment of the Northeast Corridor. Loran-C navigation accuracy was determined, as well as pilot workload conditions, during the various phases (enroute, terminal, approach) of the flights. The Northeast Corridor tests showed the compatibility of the Loran-C navigator to operate in the same airspace with other operational area navigation or conventional navigation systems using other sensor inputs (VOR/DME).

An overview of the NEC test route flown, the NEC spurs, and the final approach routes are shown in Figure B.2. The NEC test route consists of two independent routes as specified by the FAA. One proceeds northbound from the Washington, D.C./Baltimore, Maryland area through Philadelphia, New York and finally to Boston. The other companion southbound route begins at Boston and terminates in Washington, D.C. The only portion of the two test routes with common waypoints is that which passes over the urban New York City area. Also shown in Figure B.2 are the NEC feeder routes to or from Allentown, East Hartford, Camden and the New York City area, which intercept both the southbound and the northbound NEC test routes.

Tables B.1 and B.2 define the NEC southbound and northbound route flown by the USCG aircraft. The latitude and longitude coordinates were derived utilizing the given rho/theta and corresponding VORTAC shown in these tables. The waypoints on the NE Corridor route, identified by name in Figure B.2, have, in addition, been given a number for ease of identification. Additional information provided in Tables B.1 and B.2 are desired course (true and magnetic), the applicable magnetic variation in the area of each waypoint and the alongtrack distance between each waypoint. The "remarks" column on these tables briefly describes the general area of the Northeast Corridor in which each waypoint is located, as well as the designated Victor airway.

Utilization of Tables B.1 and B.2, in conjunction with Figure B.2, provides both the navigation and geographic orientation information as well as the flight test sequence. For example, from Boston to Washington, D.C., a total of 22 waypoints were required, beginning at waypoint number 1 in Boston and terminating at waypoint 22 in Washington, D.C. Similarly, in the northbound route from Washington, D.C. to Boston, a total of 20 waypoints were used. Point-in-space approaches were flown at the end of each flight. These approaches were performed at Washington, D.C. and Boston, respectively. The same point-in-space approach was flown on successive flights at each route termination. A typical flight transitioned from Otis AFB to intercept the NEC route (southbound) at waypoint 1 near Boston, proceeded direct-to waypoint 2, followed by waypoint 3, etc., until waypoint 20 was reached in the Washington, D.C. area. At this time a point-in-space approach to waypoint 22 terminated the data flight. However, following a low approach to waypoint 22, the aircraft transitioned to Andrews AFB in Washington, D.C. for final landing. The return flight (northbound) to Boston was flown on the following day.

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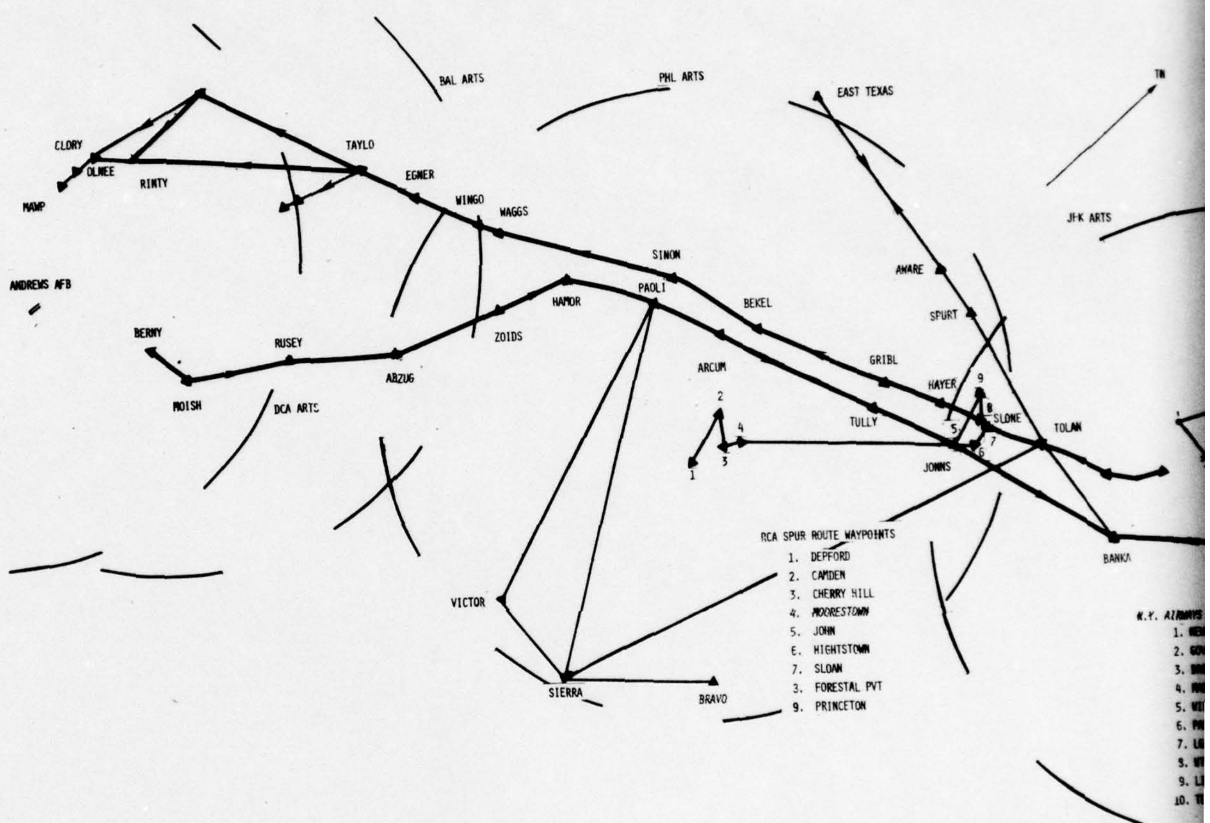
BAL ARTS
PHL ARTS
EAST TEXAS
CLORY
OLNEE
RINTY
MAWP
TAYLO
EGNER
WINGO
WAGGS
JFK ARTS
ANDREWS AFB
SINON
AWARE
PAOLI
HAMOR
BEKEL
SPURT
BERNY
RUSEY
ZOIDS
ABZUG
MOISH
DCA ARTS
ARCUM
GRIBL
HAYER
SLONE
TULLY
TOLAN
JONNS
BANKA
VICTOR
SIERRA
BRAVO
RCA SPUR ROUTE WAYPOINTS
1. DEPFORD
2. CAMDEN
3. CHERRY HILL
4. MOORESTOWN
5. JOHN
6. HIGHTSTOWN
7. SLOAN
3. FORESTAL PVT
9. PRINCETON
N.Y. AIRWAYS

Figur

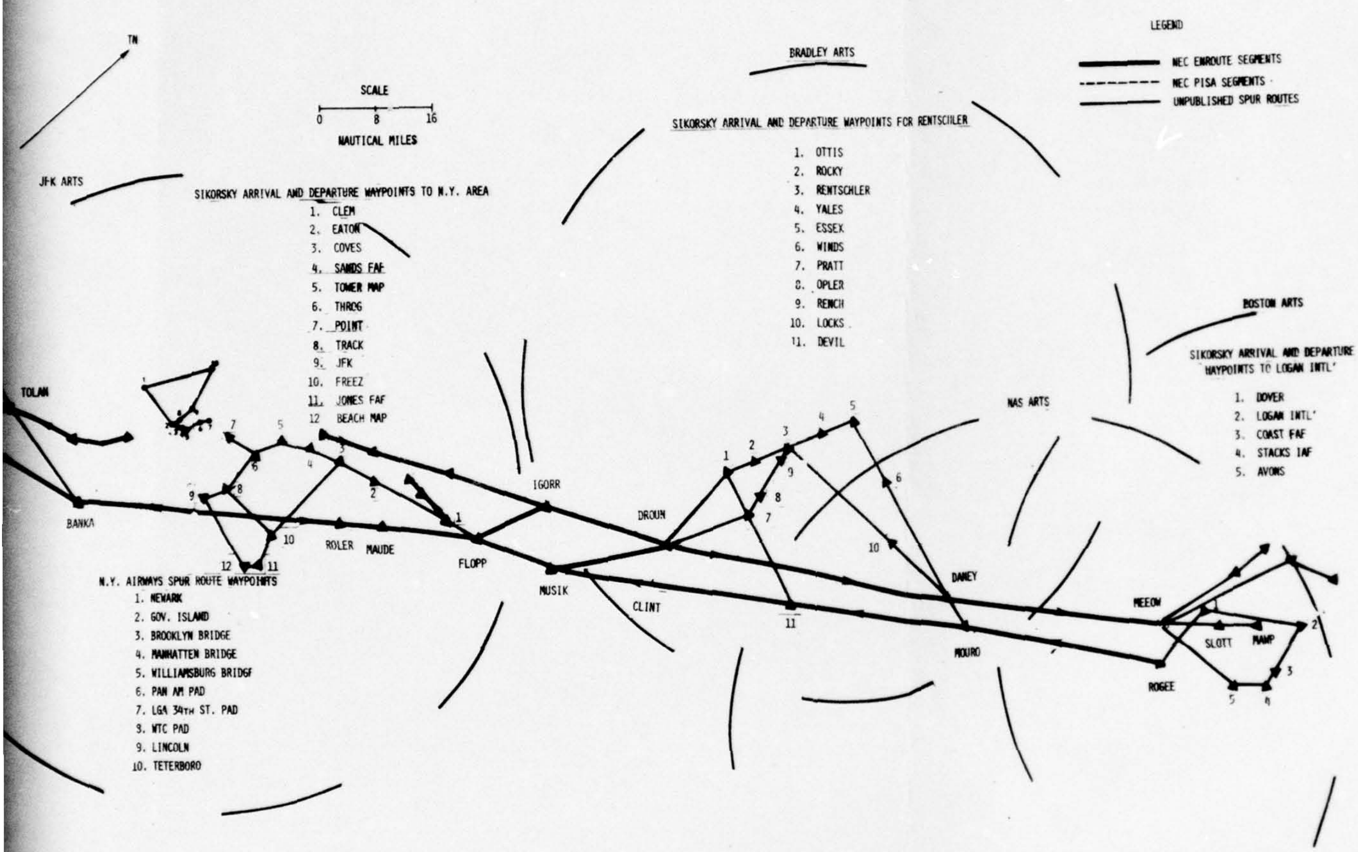

Figure B.2 Overview of the NEC Test Routes

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Table B.1 Northeast Corridor Southbound Test Route Definition (Boston-Washington)

WAYPOINT Name/Number	VOR ID	THETA (Deg.)	RHO (nm)	LATITUDE (Deg.& Min.) NORTH	LONGITUDE (Deg.& Min.) WEST	TRUE COURSE (Deg.)	MAGNETIC COURSE (Deg.)	MAGNETIC VARIATION (Deg.West)	ALONGTRACK DISTANCE (nm)	REMARKS
OTIS AFB	—	—	—	14 40.00	70 34.00	—	—	—	—	Take-off
ROGEE(1)	BOS	231.8	21.1	42 04.55	71 16.65	307.94	322.94	15	40.14	Intercept V316R(Boston)
MOURO(2)	PVD	296.9	16.0	41 46.98	71 46.72	232.02	246.02	14	28.45	Boston-NY(V316R)
CLINT(3)	MAD	124.0	04.2	41 17.32	72 36.33	231.66	244.66	13	47.53	Boston-NY(V316R)
MUSIK(4)	RVH	019.0	14.5	41 08.15	72 52.75	233.50	246.50	13	15.38	Boston-NY(V316R)
FLOPP(5)	RVH	331.8	13.0	41 03.50	73 06.12	245.30	258.30	13	11.10	Boston-NY(V316R)
MAUDE(6)	RVH	284.0	19.8	40 54.02	73 20.95	229.83	242.83	13	14.67	NY By-Pass(V313R)
ROLER(7)	JFK	061.0	20.0	40 50.67	73 26.12	229.43	240.43	11	5.15	NY By-Pass(V313R)
BANKA(8)	COL	061.0	6.5	40 22.87	74 03.07	225.46	236.46	11	39.49	NY By-Pass(V313R)
TOLAN(9)	SBJ	135.0	18.0	40 24.62	74 25.17	276.06	286.06	10	16.92	NY-Allentown(V309R)
SLONE(10)	SBJ	161.0	16.4	40 20.62	74 34.10	239.59	249.59	10	7.89	NY-DCA(V314R)
HAYER(11)	ARD	083.0	10.0	40 18.10	74 41.93	247.15	257.15	10	6.48	NY-DCA(V314R)
GRIBL(12)	ARD	144.0	01.0	40 14.50	74 53.53	247.93	257.93	10	9.55	NY-DCA(V314R)
BEKEL(13)	ARD	255.5	19.5	40 07.07	75 17.68	248.20	258.20	10	19.89	NY-DCA(V314R)
SINON(14)	MXE	039.5	08.3	40 02.22	75 34.77	249.74	258.74	9	13.95	NY-DCA(V314R)
WAGGS(15)	MXE	259.0	18.0	39 48.87	76 02.28	237.82	246.82	9	24.97	NY-DCA(V314R)
WINGO(16)	LRP	168.0	22.7	39 45.98	76 06.92	231.00	240.00	9	4.59	NY-DCA(V314R)
EGNER(17)	LRP	190.0	24.2	39 43.00	76 18.03	250.83	259.83	9	9.05	NY-DCA(V314R)
TAYLO(18)	EMI	075.0	26.0	39 39.78	76 27.63	246.50	254.50	8	8.06	NY-DCA(V314R)
RINTY(19)	EMI	187.3	13.3	39 16.40	76 58.52	225.73	233.73	8	33.40	NY-DCA(V317R)
CLORY(20)	DCA	004.0	20.8	39 12.33	77 03.62	224.17	231.17	7	5.67	DCA(IAF)
OLNEE(21)	DCA	004.5	17.5	39 09.03	77 03.18	176.36	183.36	7	3.31	DCA(FAF)
MAWP (22)	DCA	004.0	14.7	39 06.23	77 03.20	176.41	183.41	7	2.81	DCA(MAP)
ANDREWS AFB	—	—	—	38 49.00	76 53.00	155.23	162.23	7	18.97	LAND

NOTE

- 23 Segments - Total
- 387 nm - Total Alongtrack Distance
- 1 Point - Space - Approach at End of Flight (DCA)
- Waypoint Numbers Denote Sequence in which NE Corridor will be Flown (See Figure 3.2)

Table B.2 Northeast Corridor Northbound Test Route Definition (Washington-Boston)

WAYPOINT Name/Number	VOR ID	THETA (Deg.)	RHO (nm)	LATITUDE (Deg.& Min.) NORTH	LONGITUDE (Deg.& Min.) WEST	TRUE COURSE (Deg.)	MAGNETIC COURSE (Deg.)	MAGNETIC VARIATION (Deg.West)	ALONGTRACK DISTANCE (nm)	REMARKS
ANDREWS AFB	—	—	—	38 49.00	76 53.00	—	—	—	—	Take-off
BERNY(1)	BAL	151.5	12.2	39 00.45	76 30.35	056.87	064.87	8	21.02	DCA-NY (V313R)
MOISH(2)	BAL	130.0	17.7	39 00.85	76 20.37	086.99	094.99	8	7.76	DCA-NY (V313R)
RUSEY(3)	BAL	083.0	22.8	39 16.10	76 11.25	024.84	032.84	8	16.81	DCA-NY (V313R)
ABZUG(4)	ENO	308.0	24.6	39 25.77	75 58.83	044.74	053.74	9	13.63	DCA-NY (V313R)
ZOIDS(5)	EWT	283.0	11.2	39 41.12	75 51.83	019.33	028.33	9	16.27	DCA-NY (V313R)
HAMOR(6)	EWT	333.0	13.4	39 51.18	75 47.58	017.96	026.96	9	10.58	DCA-NY (V313R)
PAOLI(7)	EWT	021.5	18.6	39 58.52	75 32.07	058.24	067.24	9	13.98	DCA-NY (V313R)
ARCUM(8)	ARD	246.0	24.5	40 01.45	75 21.00	070.88	080.88	10	8.97	DCA-NY (V313R)
TULLY(9)	ARD	166.0	05.0	40 10.62	74 51.82	067.51	077.51	10	24.13	DCA-NY (V313R)
JOHNS(10)	RBV	317.0	06.2	40 15.87	74 36.22	066.13	076.13	10	13.02	DCA-NY (V313R)
BANKA(11)	COL	061.0	06.5	40 22.87	74 03.07	074.34	085.34	11	26.23	DCA-NY (V313R)
ROLER(12)	JFK	061.0	20.0	40 50.67	73 26.12	045.06	056.34	11	39.49	NY By-Pass (V313R)
MAUDE(13)	RVH	284.0	19.8	40 54.02	73 20.95	049.38	062.38	13	5.15	NY By-Pass (V313R)
FLOPP(14)	RVH	331.8	13.0	41 03.50	73 06.12	049.66	062.66	13	14.67	NY By-Pass (V313R)
IGORR(15)	RVH	359.8	20.2	41 13.38	73 00.90	021.67	034.67	13	10.63	NY By-Pass (V313R)
DROUN(16)	MAD	024.9	02.9	41 21.65	72 40.77	061.22	074.22	13	17.24	NY-Boston (V315R)
DANEY(17)	PVD	297.0	21.9	41 48.32	71 54.43	052.17	066.17	14	43.73	NY-Boston (V315R)
MEEOW(18)	BOS	245.4	20.4	42 08.42	71 20.82	051.00	066.00	15	32.07	NY-Boston (V315R)IAF
SLOTT(19)	BOS	246.3	11.9	42 14.00	71 12.17	048.91	063.91	15	6.50	Boston (FAF)
MAWP (20)	BOS	248.1	6.4	42 17.62	71 06.55	049.19	064.19	15	5.51	Boston (MAP)
OTIS AFB	—	—	—	41 40.00	70 34.00	147.07	162.07	15	44.70	Land

NOTE

- 21 Segments - Total
- 394 nm - Total Alongtrack Distance
- 1 Point-Space - Approach at End of Flight (Boston)
- Waypoint Numbers Denote Sequence in which NE Corridor will be Flown (See Figure 3.2)

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The northbound flight consisted of a transition from Andrews AFB to intercept the NEC route (northbound) at waypoint 1 in the Washington, D.C./Baltimore area. The data flight terminated at the conclusion of the point-in-space approach (waypoint 20) in the Boston area. The test aircraft then proceeded direct to Otis AFB and landed. Data collection for Loran-C performance was initiated during the transition to waypoint 1 as soon as a sufficient altitude for radar lock-on was achieved and terminated when lock-on was lost during the transition to Otis AFB.

Table B.3 presents a detailed description of the NE Corridor flight test scenario for each flight. The footnotes at the bottom of Table B.3 summarizes some of the general test characteristics of the NEC applicable to the five flights. Number of segments flown, total alongtrack distance, Loran-C update mode, cruise altitudes and subject pilot are each defined by flight test number. It should be noted that the altitude at which the aircraft was flown was critical since ARTS III and IA tracking was used to derive actual aircraft position. During certain portions of the NEC flights tests, low altitudes were chosen to gather needed data on Loran-C and VOR/DME signal coverage. As a result, much ARTS tracking data was lost on these flights.

Integral to the overall north and south flying of the Northeast Corridor routes was specific data collection and operational evaluation of existing transition or spur routes currently in use when flying to or from the corridor. The following discussion describes how the NEC spurs (Sikorsky, Allentown, RCA, etc.) interacted with the NEC routes and flight test schedule. The relative location and geometry of these spurs was previously illustrated in Figure B.2. The exact sequence of the flights on the NEC, with the spurs integrated, is shown in Table B.4. This table summarizes (by flight number) the direction of flight, the specific routing, the type of approach flown and the total duration of each flight. As indicated in the table, the predominant type of approach was the point-in-space approach (PISA) designed specifically for IFR helicopter operations in the NEC. Each of the straight-through flights (numbers 1, 3, 4 and 5) included PISA's. The approach at NAFEC (flight 2) was a non-precision approach (NPA) conducted using area navigation procedures and Loran-C navigation information.

The specific detailed breakdown of the integrated NEC/spur flight test program as flown is summarized in Figure B.3. A total of 53 hours flown; 35 for the basic USCG tests (22 hours in the HH52 and 13 hours in the HH3) and 18 for the FAA add-on tests. The 22 hours of HH52 NEC tests are further broken down into five flights. Each of flights 1, 4 and 5 encompasses a one-way trip the entire length of the NEC. Flights 2 and 3 combined, encompass one one-way trip. Flights 1, 2 and 3, have additional "spur" routes which were tested. The Sikorsky, RCA, Mack Truck and New York Airways spurs will be discussed subsequently. The 13 hours of HH3 NEC testing were broken down into two flights. Flight 6 encompassed two one-way trips the entire length of the NEC southbound and one northbound with a transition to NAFEC. Flight 7 encompassed a one-way trip from NAFEC to the NEC northbound. NEC cruise altitudes were flown in the following order: 4500 feet for the NEC routes and MEAs for the

Table B.3 Northeast Corridor Flight Test Data Collection Summary

FLIGHT	ROUTE	AIRSPACE	NUMBER OF SEGMENTS	TOTAL ALONG TRACK DISTANCE (nm)	UPDATE (yes/no)	CRUISE ALTITUDE MSL
1	BOSTON-DCA	ENROUTE	19	322.19	NO	T/O to 4500'
	AT DCA	POINT-IN-SPACE APPROACH	2	6.12		1200'
	DCA-ANDREWS	TRANSITION	1	18.97		1200'-Land
	TOTALS		22	347.28		
2	ANDREWS-NEC	TRANSITION	1	21.02	NO	T/O to 4500"
	NEC-PHILADELPHIA	ENROUTE	6	79.03		4500'
	PHILADELPHIA-NAFEC	ENROUTE	1	56.59		4500'
	AT NAFEC	APPROACH	2	11.00		4500'-Land
	TOTALS		10	167.64		
3	NAFEC-PHILADELPHIA	ENROUTE	2	67.59	YES	T/O to 4500'
	PHILADELPHIA-BOSTON	ENROUTE	11	235.33		4500'
	AT BOSTON	POINT-IN-SPACE APPROACH	2	14.01		1200'
	BOSTON-OTIS	TRANSITION	1	44.70		1200'-Land
	TOTALS		16	361.63		
4	OTIS-BOSTON	TRANSITION	1	40.14	YES	T/O to MEA
	BOSTON-DCA	ENROUTE	19	322.19		MEA
	AT DCA	POINT-IN-SPACE APPROACH	2	6.12		1200'-Land
	TOTALS		22	368.45		
5	DCA-NEC	TRANSITION	1	11.38	YES	T/O to MEA
	NEC-BOSTON	ENROUTE	17	314.36		MEA
	AT BOSTON	POINT-IN-SPACE APPROACH	2	14.01		1200'
	BOSTON-OTIS	TRANSITION	1	44.70		1200'-Land
	TOTALS		21	384.45		
6	OTIS-BOSTON	TRANSITION	1	40.14	NO	T/O to 4500'
	BOSTON-DCA	ENROUTE	19	322.19		4500'
	AT DCA	POINT-IN-SPACE APPROACH	2	6.12		1200'
	DCA-ANDREWS	TRANSITION	1	18.97		1200'-Land
	ANDREWS-NEC	TRANSITION	1	21.02		T/O to 4500'
	NEC-PHILADELPHIA	ENROUTE	6	79.03		4500'
	PHILADELPHIA-NAFEC	ENROUTE	1	56.59		4500'
	AT NAFEC	APPROACH	2	11.00		4500'-Land
	TOTALS		32	555.06		
7	NAFEC-PHILADELPHIA	ENROUTE	2	67.59	NO	T/O to 4500'
	PHILADELPHIA-BOSTON	ENROUTE	11	235.33		4500'
	AT BOSTON	POINT-IN-SPACE APPROACH	2	14.01		1200'
	BOSTON-OTIS	TRANSITION	1	44.70		1200'-Land
	TOTALS		16	361.63		

/NOTE/
- 7 Flights - Total
- 139 Segments - Total
- 2546 nm - Total Along Track Distance
- Loran-C Lat/Lon (with update): 3 Flights
- 6 Point-in-Space Approaches: DCA (3) - Boston (3)
- 2 Non-Precision Approach at NAFEC
- Loran-C Lat/Lon (without update): 4 Flights

Table B.4 HH52 and HH3 Northeast Corridor And Spur Test Descriptions

FLIGHT NUMBER	DIRECTION OF FLIGHT	ROUTE	APPROACH TYPE	TOTAL FLIGHT TIME (Hrs)
1	Southbound	BOS - East Hartford Via Sikorsky Spurs - NY Area via Sikorsky and New York Airways Spurs - DCA - Andrews AFB	PISA*	12.9
2	Northbound NEC to NAFEC	Andrew AFB - DCA - PHL via RCA Spur - NAFEC	PISA NPA†	5.4
3	Northbound	NAFEC - PHL - JFK - BOS via Allentown Spur and Sikorsky Spur - Otis AFB	PISA	12.0
4	Southbound	Otis AFB - BOS - JFK - DCA	PISA	4.8
5	Northbound	DCA - JFK - BOS - Otis AFB	PISA	4.9
6**	Southbound	Otis AFB - BOS - JFK - DCA - Andrews AFB - PHL - NAFEC	PISA NPA	5.0
7	Northbound	NAFEC - PHL - JFK - BOS - Otis AFB	PISA	3.3

NOTE: *PISA - Point-In-Space Approach
†NPA - Non-Precision Approach
**An addition 4.5 hours were flown from Otis AFB to DCA

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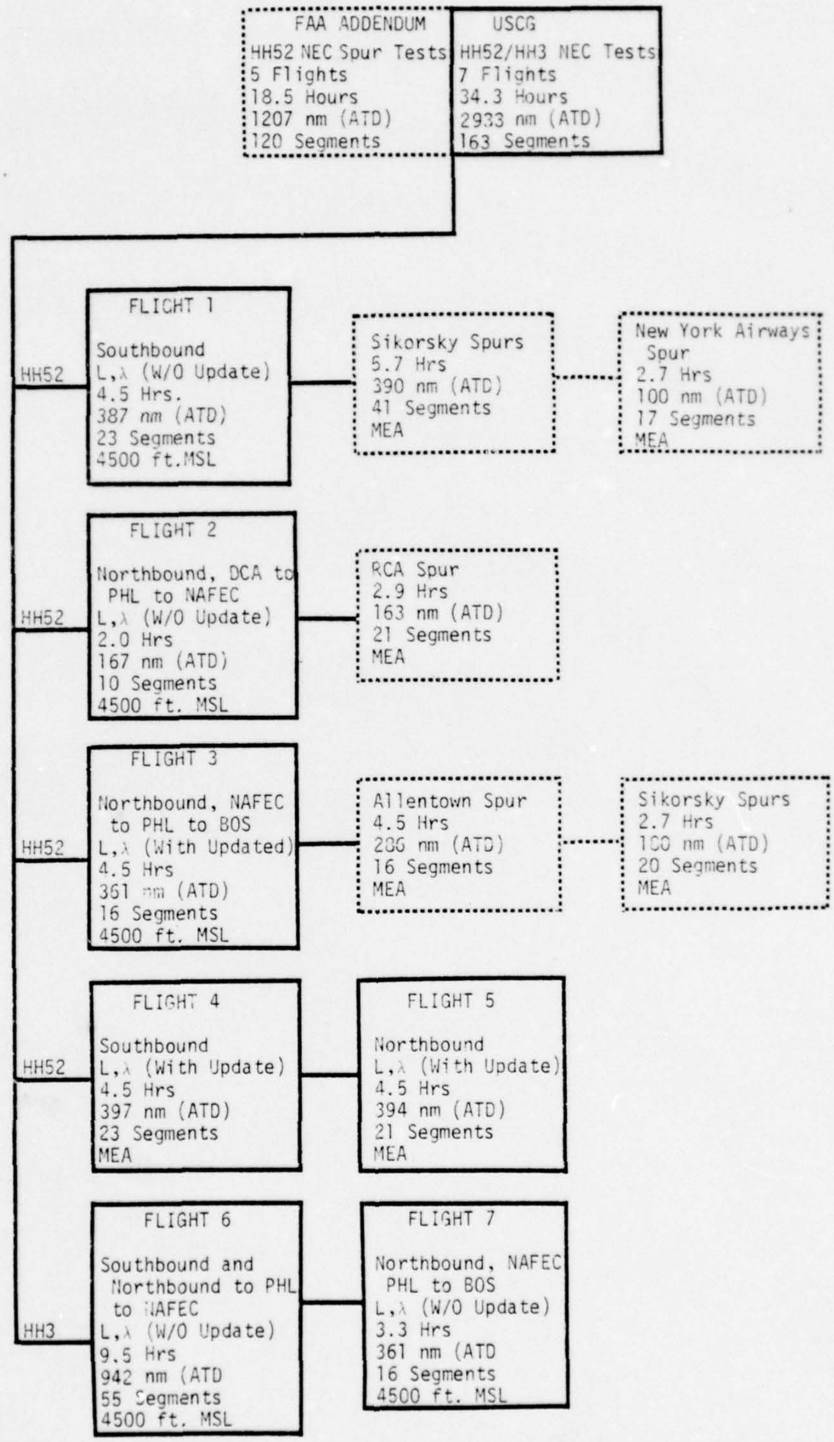

/NOTE/ The HH3 flew an additional 4.5 hrs., 387 nm and 23 segments for Flight 6 (Otis AFB to DCA)

Figure B.3 Summary of the Integrated NEC/Spur Flight Test Program

spurs during flights 1, 2 and 3. Flights 4 and 5 were flown at MEAs or lower. HH3 NEC test flights 6 and 7 were flown at 4500 feet MSL. A final important point illustrated in Figure B.3 is that all the NEC flights were flown in the latitude/longitude waypoint input mode. Flights 1, 2, 6 and 7 were flown using charted lat/lon waypoint coordinates without a pre-flight Loran-C position update on the helipad prior to departure. Flights 3, 4 and 5 were flown using charted lat/lon waypoint coordinates with a position update.

Sikorsky Spurs

The Sikorksy Spurs totaling about eight hours were incorporated into NEC flights 1 and 3 to accommodate the complexity of the Sikorsky northbound and southbound route structure. Figure B.4 presents, in detail, the Sikorsky spurs illustrated schematically in Figure B.2. The dashed lines represent the NEC route in this figure. Flight profile A shows the southbound Sikorsky spurs as they impacted the NEC from Boston to the Rentschler area. Flight profile B shows the northbound Sikorsky spurs as they impacted the NEC in the New York areas. Table B.5 provides a breakdown of the Sikorsky spurs by enroute, point-in-space approaches and departures with the corresponding number of segments. Items of importance are the total along track distance (ATD) in nm and total hours for each profile. The summary shows a total of 33 enroute segments, nine point-in-space approaches (comprising 20 segments) and eight departures (comprising eight segments), all of which total 61 segments (570 nm and 8.4 hours for the Sikorsky spurs).

Table B.6 provides the Sikorsky waypoint names and corresponding number with desired course, magnetic variation, and along track distance between each waypoint.

New York Airways Spurs

New York Airways is a commercial transportation corporation operating on approved VFR helicopter routes between LaGuardia, J.F. Kennedy, Newark and the World Trade Center. Because New York Airways helicopters are not equipped with precision navigation instrumentation, the routes are flown with visual reference points. The acceptability of Loran-C navigation in this airspace environment is pertinent to this test, therefore; the following plan was devised:

> The New York Airways (spur) routes were flown on flight 1, as shown previously in Figure B.3, after the Sikorsky (spur) routes were flown. This test consisted of one flight for 2.0 hours encompassing 114 nm (ATD). Figure B.5 pictorially illustrates the New York Airways spurs identifying route segments and direction of flight to LGA, E. 34th Street, Pan Am Metroport, Newark Ramp, the World Trade Center heliport, and Teterboro. Table B.7 provides data for routes 1 and 2 point-in-space approach (PISA), including total ATD in nm and total hours.

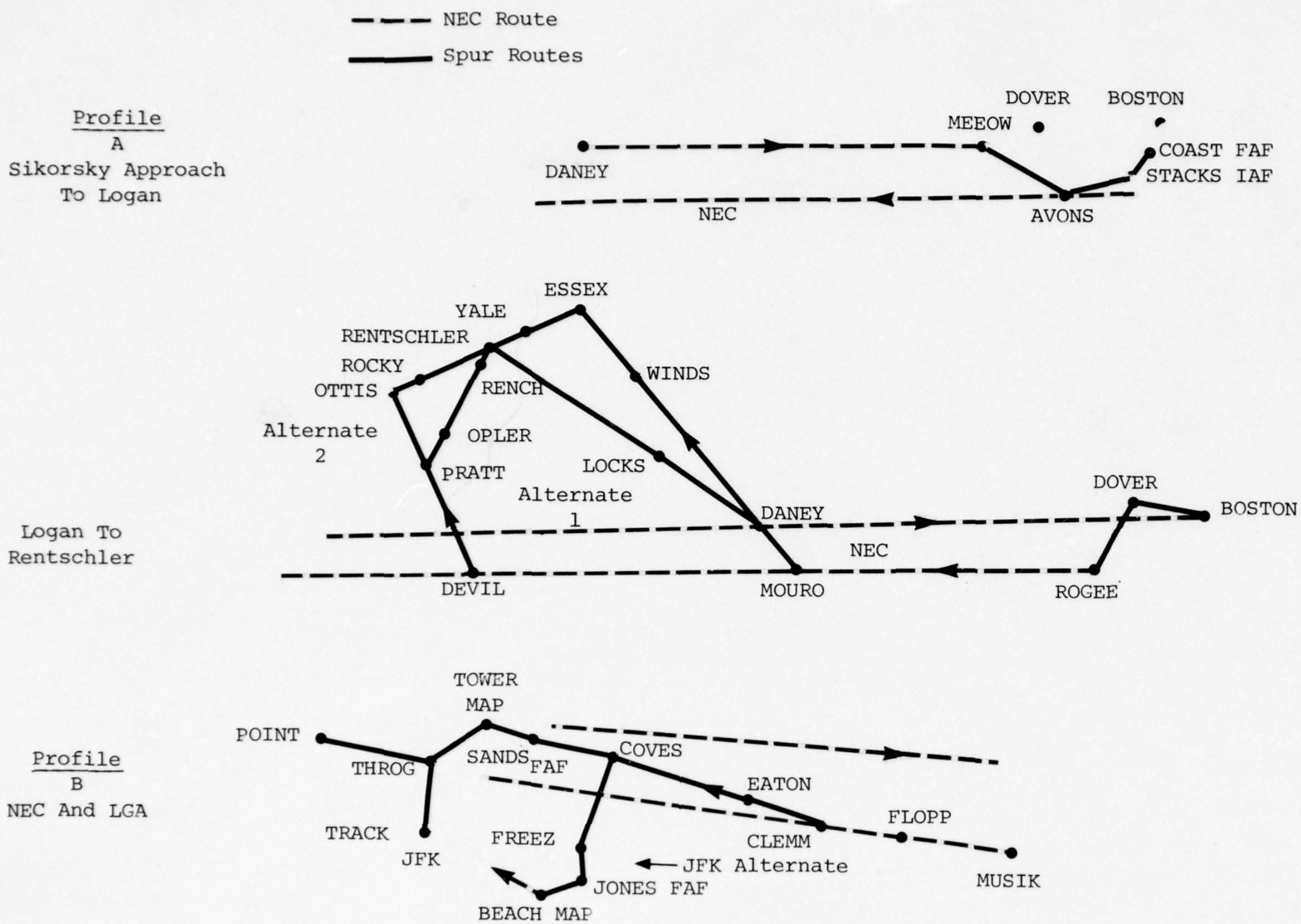

Figure B.4 Flight Test Scenario Profiles For Sikorsky Spurs (Not to Scale)

Table B.5 Flight Test Scenario For Sikorsky Spur Routes

PROFILE ROUTE	AIRSPACE	NO. OF SEGMENTS	TOTAL ATD (nm)/HRS.
A. Sikorsky Approach to Logan: Logan to Rentschler	(1) PISA to Logan	3	420/6.2
	(1) Departure from Logan	3	
	Enroute	27	
	(5) PISA to Rentschler	9	
	(5) Departure from Rentschler	3	
TOTAL		45	
B. NEC to JFK and LGA	Enroute	6	150/2.2
	(1) PISA to LGA	3	
	(1) Departure from LGA	1	
	(2) PISA to JFK	5	
	(1) Departure from JFK	1	
TOTAL		16	
Summary	Enroute	33	
	(9) PISA	20	
	(8) Departures	8	
	TOTAL	61	570/8.4

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Table B.6 Sikorsky Spur Route Definition Date

WAYPOINT*		MEA*	LATITUDE	LONGITUDE	TRUE COURSE	MAG. VAR.	ALONGTRACK DISTANCE
NAME	NUMBER	(feet MSL)	(deg. - min.)	(deg. - min.)	(deg.)	(deg.)	(nm)
+MEEOW	1	3000'	42° 08.42'	71° 20.82'	———	15° W	———
STACKS IAF	2	1500'	42° 12.75'	70° 57.07	44.55	15° W	4.94
COAST FAF	3	1000'	42° 15.13'	70° 57.68	349.26	15° W	2.42
DOVER	4	1500'	42° 03.70'	71° 14.60'	———	15° W	———
+ROGEE	5	4500'	42° 04.55'	71° 16.65'	299.19	15° W	1.74
+DANEY	6	2000'	41° 47.98'	71° 54.17'	———	14° W	———
WINDS	7	1500'	41° 52.10'	72° 19.05'	282.67	14° W	18.9
ESSEX	8	1500'	41° 54.32'	72° 32.43'	282.63	14° W	10.2
YALES	9	1500'	41° 48.95'	72° 35.10'	200.33	14° W	5.72
RENTSCHLER	10	640'	41° 44.87'	72° 37.42'	202.98	13° W	4.43
LOCKS	11	1500'	41° 46.77'	72° 11.03'	84.34	14° W	19.7
+DANEY	12	2000'	41° 47.98'	71° 54.17'	84.40	14° W	12.6
+MAURO	13	2000'	41° 46.98'	71° 46.72'	100.16	14° W	5.64
DEVIL	14	2000'	41° 30.00'	72° 15.20'	231.57	14° W	27.2
PRATT	15	2000'	41° 33.63'	72° 33.43'	284.99	13° W	14.1
OPLER	16	1500'	41° 36.90'	72° 34.48;	346.50	13° W	3.36
RENTCH	17	640'	41° 43.27'	72° 36.82'	344.66	13° W	6.60
RENTSCHLER	18	640'	41° 44.87'	72° 37.42'	344.37	13° W	1.66
ROCKY	19	1500'	41° 38.92'	72° 40.23'	199.43	13° W	6.30
OTTIS	20	1500'	41° 35.51'	72° 41.87'	199.79	13° W	3.62
DROUN	21	2000'	41° 21.65'	72° 40.77'	173.76	13° W	13.46
PRATT	22	2000'	41° 33.63'	72° 33.43'	24.62	31° W	13.18
+FLOPP	23	4500'	41° 03.50'	73° 06.12'	———	13° W	———
+CLEMM	24	1500'	41° 01.70'	73° 11.68'	246.80	12° W	4.56
+EATON	25	1500'	40° 58.55'	73° 24.93'	252.58	12° W	10.4
+COVES	26	1200'	40° 56.15'	73° 33.98'	250.70	12° W	7.24
SANDS FAF	27	1200'	40° 53.63'	73° 40.60'	243.29	12° W	5.60
TOWER MAP	28	1200'	40° 51.77'	73° 44.20'	235.67	12° W	3.29
THROG	29	500'	40° 48.03'	73° 46.50'	204.96	12° W	4.12
POINT	30	500'	40° 46.65'	73° 51.93'	251.47	12° W	4.33
THROG	31	500'	40° 48.03'	73° 46.50'	71.41	12° W	4.33
TRACK	32	500'	40° 41.08'	73° 44.98'	170.58	12° W	7.04
JFK	33	500'	40° 38.20'	73° 46.97'	207.67	12° W	3.25
TRACK	34	500'	40° 41.08'	73° 44.98'	27.65	12° W	3.25
FREEZ	35	1200'	40° 42.03'	73° 33.10'	83.91	12° W	9.05
JONES FAF	36	1200'	40° 37.53'	73° 30.67'	157.71	12° W	4.86
BEACH MAP	37	1200'	40° 35.85'	73° 32.13'	213.42	12° W	2.01
JFK	38	500'	40° 38.20'	73° 46.97'	205.89	12° W	2.96

*/NOTE/ * Waypoint information is based on UTC Discrete Helicopter RNAV Routes 2/15/78
+ NEC Waypoints

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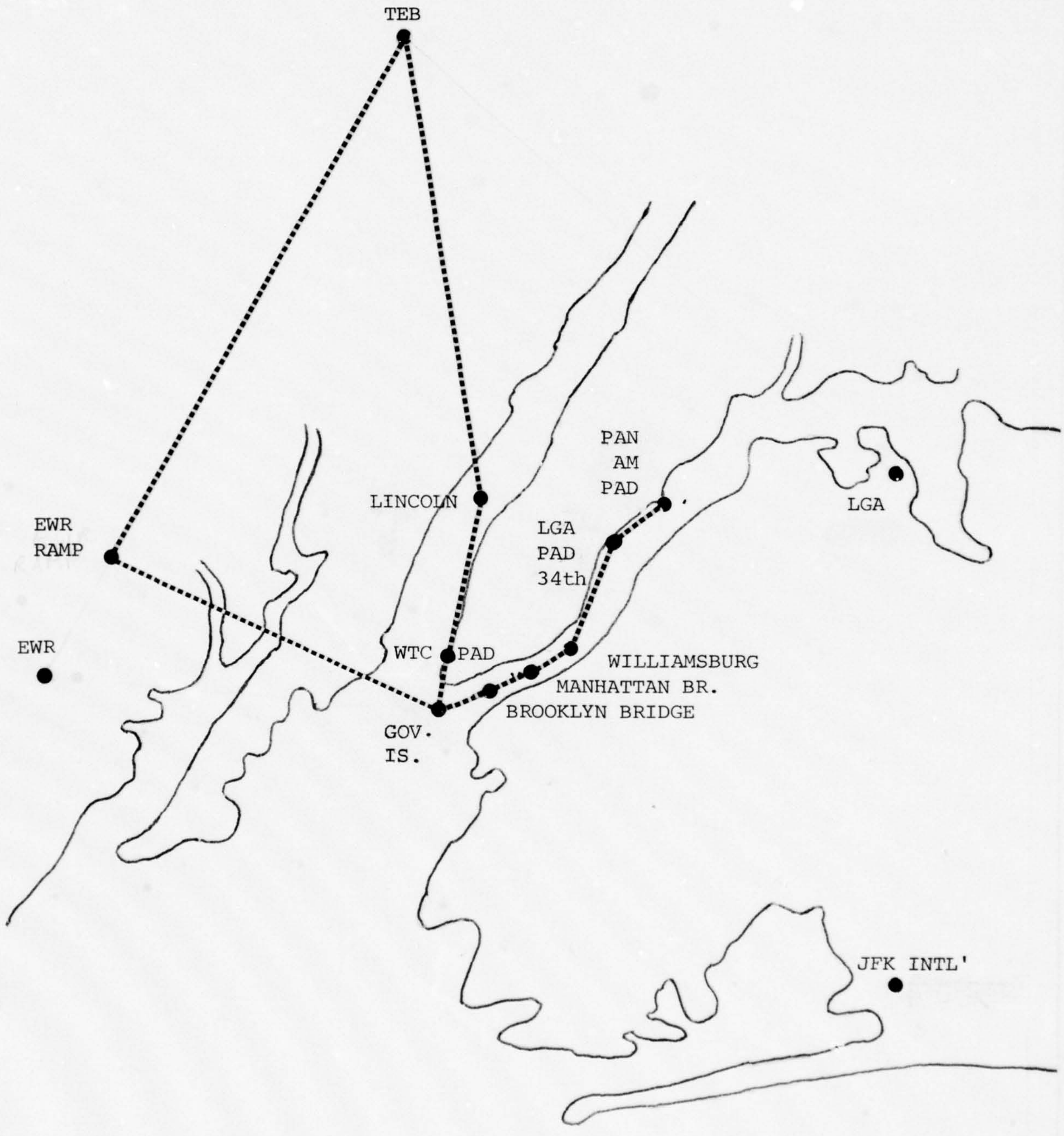

/NOTE/ EWR Ramp is also known as EWR Dock

Figure B.5 N.Y. Airways Spur Routes Profile

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Table B.7 New York Airways Spur Route Scenario

ROUTE*	AIRSPACE SEGMENTS		ATD (nm)	HOURS
	Enroute	PISA†		
1 (WPs 1-28)	19	8 (9)	49.1	1.4
2 (WPs 29-56)	21	7 (7)	50.9	1.3

*Waypoint Numbers are identified in Table B.8

†Parenthetical numbers identify the number of PISAs flown

Route 1 defines waypoints listed in Table B.8 by numbers 1 through 28. Route 2 defines waypoints listed in Table B.8 numbers 20 through 46. As seen in Table B.7, there are a total of 40 enroute segments and 16 PISAs. Table B.8 presents in detail the New York Airways (spur) route definition for each segment. This information includes each waypoint name and number, latitude, longitude, true course, magnetic variation and along track distance. Each waypoint in this table corresponds to a visual reference or heliport lat/lon.

Data was recorded with the airborne data recorder. The New York ARTS facility was not able to provide tracking for data extraction.

MACK Truck (Allentown) Spur

The Allentown spur is a straight line FAA approved RNAV route segment exiting the NEC in a westwardly direction. This segment was flown on USCG NEC flight 3 as shown previously in Figure B.3. Figure B.6 presents the Allentown spur profile. This spur was flown two round trips from the NEC northbound route waypoint, BANKA, to a point-in-space approach to EAST TEXAS waypoint near Allentown. This provided approximately 4.5 hours and 286 nm (ATD).

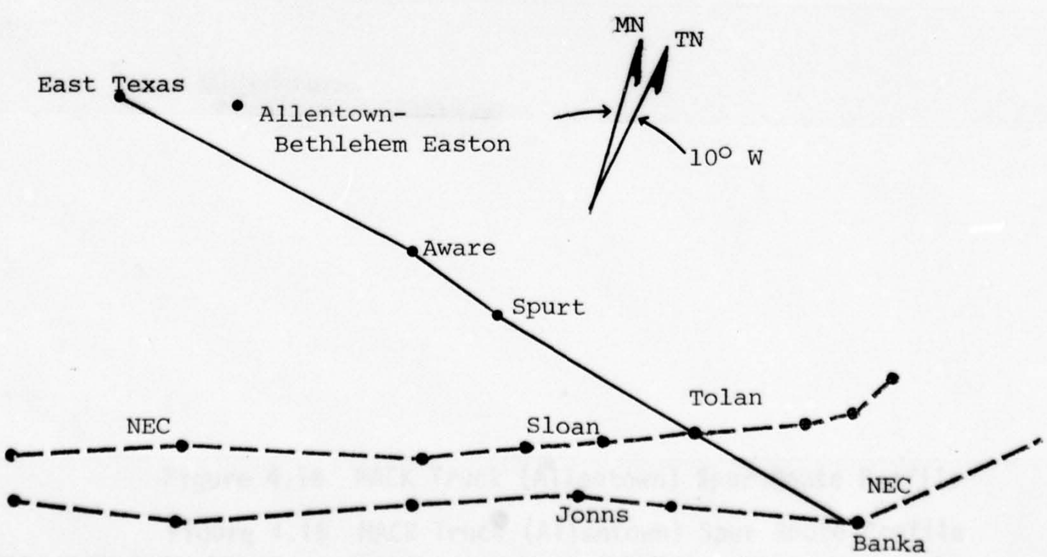

Figure B.6 Mack Track (Allentown) Spur Route Profile

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Table B.8 New York Airways Route Definition

WAYPOINT NAME	WAYPOINT NUMBER	MEA (feet MSL)	LATITUDE (deg.-min.)	LONGITUDE (deg.-min.)	TRUE COURSE (deg.)	MAG. VAR. (deg.)	ALONGTRACK DISTANCE (nm)
PAN AM METROPORT	1	3000'	40° 45.60'	73° 57.43'	——	11° W	——
LGA E. 34th ST.	2	3000'	40° 44.55'	73° 58.35'	213.58	11° W	1.26
WILLIAMSBURG BRIDGE	3	3000'	40° 43.12'	73° 58.13'	173.34	11° W	1.43
MANHATTAN BRIDGE	4	3000'	40° 42.29'	73° 59.15'	222.97	11° W	1.13
BROOKLYN BRIDGE	5	3000'	40° 42.30'	74° 00.00'	270.89	11° W	.64
GOVERNORS ISLAND	6	3000'	40° 41.42'	74° 1.14'	224.49	11° W	1.23
WTC PAD	7	3000'	40° 42.28'	74° 01.08'	3.03	11° W	.86
GOVERNORS ISLAND	8	3000'	40° 41.42'	74° 1.14'	183.03	11° W	.86
EWR RAMP	9	3000'	40° 44.33'	74° 09.93'	293.64	11° W	7.27
TETERBORO	10	3000'	40° 50.95'	74° 03.78'	35.08	11° W	8.09
LINCOLN	11	3000'	40° 45.45'	74° 0.47'	155.49	11° W	6.04
GOVERNORS ISLAND	12	3000'	40° 41.42'	74° 1.14'	187.18	11° W	4.06
BROOKLYN BRIDGE	13	3000'	40° 42.30'	74° 00.00'	44.47	11° W	1.23
MANHATTAN BRIDGE	14	3000'	40° 42.29'	73° 58.15'	90.89	11° W	.64
WILLIAMSBURG BRIDGE	15	3000'	40° 43.12'	73° 53.13'	79.65	11° W	4.63
LGA E. 34th ST.	16	3000'	40° 44.55'	73° 58.35'	289.90	11° W	4.20
WILLIAMSBURG BRIDGE	17	3000'	40° 43.12'	73° 58.13'	173.34	11° W	1.43
MANHATTAN BRIDGE	18	3000'	40° 42.29'	73° 59.15	222.97	11° W	1.13
BROOKLYN BRIDGE	19	3000'	40° 42.30'	74° 00.00'	269.99	11° W	.64
GOVERNORS ISLAND	20	3000'	40° 41.42'	74° 1.14'	224.82	11° W	1.22
EWR RAMP	21	3000'	40° 44.33'	74° 09.93'	293.64	11° W	7.27
GOVERNORS ISLAND	22	3000'	40° 41.42'	74° 1.14'	113.54	11° W	7.27
WTC PAD	23	3000'	40° 42.28'	74° 01.08'	3.03	11° W	.86
GOVERNORS ISLAND	24	3000'	40° 41.42'	74° 1.14'	183.03	11° W	.86
BROOKLYN BRIDGE	25	3000'	40° 42.30'	74° 00.00'	44.47	11° W	1.23
MANHATTAN BRIDGE	26	3000'	40° 42.29'	73° 59.15'	90.89	11° W	.64
WILLIAMSBURG BRIDGE	27	3000'	40° 43.12'	73° 58.13'	42.95	11° W	1.13
LGA E. 34th ST.	28	3000'	40° 44.55'	73° 58.35'	353.35	11° W	1.43
PAN AM METROPORT	29	3000'	40° 45.60'	73° 57.43'	33.56	11° W	1.26

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Table B.8 New York Airways Route Definition
(continued)

WAYPOINT		MEA	LATITUDE	LONGITUDE	TRUE COURSE	MAG. VAR.	ALONGTRACK DISTANCE
NAME	NUMBER	(feet MSL)	(deg.-min.)	(deg.-min.)	(deg.)	(deg.)	(nm)
WILLIAMSBURG BRIDGE	30	3000'	40° 43.12'	73° 58.13'	192.08	11° W	2.54
MANHATTAN BRIDGE	31	3000'	40° 42.29'	73° 59.15'	222.97	11° W	1.13
BROOKLYN BRIDGE	32	3000'	40° 42.30'	74° 00.00'	270.89	11° W	.64
GOVERNORS ISLAND	33	3000'	40° 41.42'	74° 1.14'	224.49	11° W	1.23
EWR RAMP	34	3000'	40° 44.33'	74° 09.93'	293.64	11° W	7.27
GOVERNORS ISLAND	35	3000'	40° 41.42'	74° 1.14'	113.54	11° W	7.27
BROOKLYN BRIDGE	36	3000'	40° 42.30'	74° 00.00'	44.80	11° W	1.22
MANHATTAN BRIDGE	37	3000'	40° 42.29	73° 59.15'	90.00	11° W	.64
WILLIAMSBURG BRIDGE	38	3000'	40° 43.12'	73° 58.13'	42.95	11° W	1.13
LGA E. 34th ST.	39	3000'	40° 44.55'	73° 58.35'	353.35	11° W	1.43
WILLIAMSBURG BRIDGE	40	3000'	40° 43.12'	73° 58.13'	173.34	11° W	1.43
MANHATTAN BRIDGE	41	3000'	40° 42.29'	73° 59.15'	222.97	11° W	1.13
BROOKLYN BRIDGE	42	3000'	40° 42.30'	74° 00.00	270.89	11° W	.64
GOVERNORS ISLAND	43	3000'	40° 41.42'	74° 1.14'	224.49	11° W	1.23
LINCOLN	44	3000'	40° 45.45'	74° 0.47'	7.17	11° W	4.06
TETERBORO	45	3000'	40° 50.95'	74° 03.78'	335.52	11° W	6.04
EWR RAMP	46	3000'	40° 44.33'	74° 09.93'	215.15	11° W	8.09
GOVERNORS ISLAND	47	3000'	40° 41.42'	74° 1.14'	113.54	11° W	7.27
BROOKLYN BRIDGE	48	3000'	40° 42.30'	74° 00.00'	44.47	11° W	1.23
MANHATTAN BRIDGE	49	3000'	40° 42.29'	73° 59.15'	90.89	11° W	.64
WILLIAMSBURG BRIDGE	50	3000'	40° 43.12'	73° 58.13'	42.95	11° W	1.13
LGA E. 34th ST	51	3000'	40° 44.55'	73° 58.35'	353.35	11° W	1.43
WILLIAMSBURG BRIDGE	52	3000'	40° 43.12'	73° 58.13'	173.34	11° W	1.43
MANHATTAN BRIDGE	53	3000'	40° 42.29'	73° 59.15'	222.97	11° W	1.13
BROOKLYN BRIDGE	54	3000'	40° 42.30'	74° 00.00	270.89	11° W	.64
GOVERNORS ISLAND	55	3000'	40° 41.42'	74° 1.14'	224.49	11° W	1.23
EWR RAMP	56	3000'	40° 44.33'	74° 09.93'	293.64	11° W	7.27

Table B.8 presents a breakdown of these hours and nautical miles. This table divides the two round trips into four one-way trip profiles A-D identifying enroute segments, PISA segments, and the corresponding hours and nautical miles. Each one-way trip equals about 75.7 nm and 1.0 hour of flight time, except for profile D where the aircraft transitioned to the NEC southbound at TOLAN.

Table B.9 Flight Test Scenario for the Allentown Spur Route

PROFILE	ROUTE	AIRSPACE	NO. OF SEGMENTS	TOTAL ATD/hrs.
A	BANKA to EAST TEXAS	Enroute PISA*	3 1	75.7 nm/1.6
TOTAL			4	
B	EAST TEXAS to BANKA	Enroute	4	75.7 nm/0.9
C	BANKA to EAST TEXAS	Enroute PISA	3 1	75.7 nm/1.3
TOTAL			4	
D	EAST TEXAS to TOLAN	Enroute	4	58.8 nm/0.7
SUMMARY		Enroute 2 PISAs	14 2	286 nm/4.5
TOTAL			16	

*PISA - Point-in-Space Approach

Table B.10 provides the Allentown spur route definition including waypoint names and numbers with minimum enroute altitudes (MEA), true course, magnetic variation and alongtrack distance.

RCA Spur

The RCA spur routes are currently in use in VFR operations only. These routes were flown on flight 2, as previously shown in Figure B.3, prior to flying to NAFEC. This test consisted of one flight of 163 nm of along track distance entailing 2.9 flight hours. Figure B.7 presents the RCA spur route profile illustrating its relationship to the NEC. Table B.11 presents the RCA spur test sequence identifying enroute segments and point-in-space approaches. This table defines two basic routes, Deptford Princeton via Sloan and Princeton to Deptford via Jonns. As seen from the table, this test produces a total of 21 enroute segments and 17 point-in-space approaches. Table B.12 provides the RCA spur route definition for each waypoint including MEAs, true course, magnetic variation and along track distance.

Table B.10 Allentown Spur Test Route Definition

WAYPOINT		MEA (feet MSL)	LATITUDE	LONGITUDE	TRUE COURSE (Deg.)	MAGNETIC VARIATION (Deg.)	ALONGTRACK DISTANCE (nm)
NAME	NUMBER		(Deg., Min.)	(Deg., Min.)			
BANKA	1	2000'	40° 22.9'	75° 03.1'		10° W	
TOLAN	2	2300'	40° 24.6'	74° 25.2'	275.9	10° W	16.9
SPURT	3	2300'	40° 30.1'	74° 50.6'	286.0	10° W	20.1
AWARE	4	2700'	40° 31.3'	75° 02.3'	277.7	10° W	9.0
EAST TEXAS	5	2700'	40° 34.9'	75° 41.1'	277.2	10° W	29.7

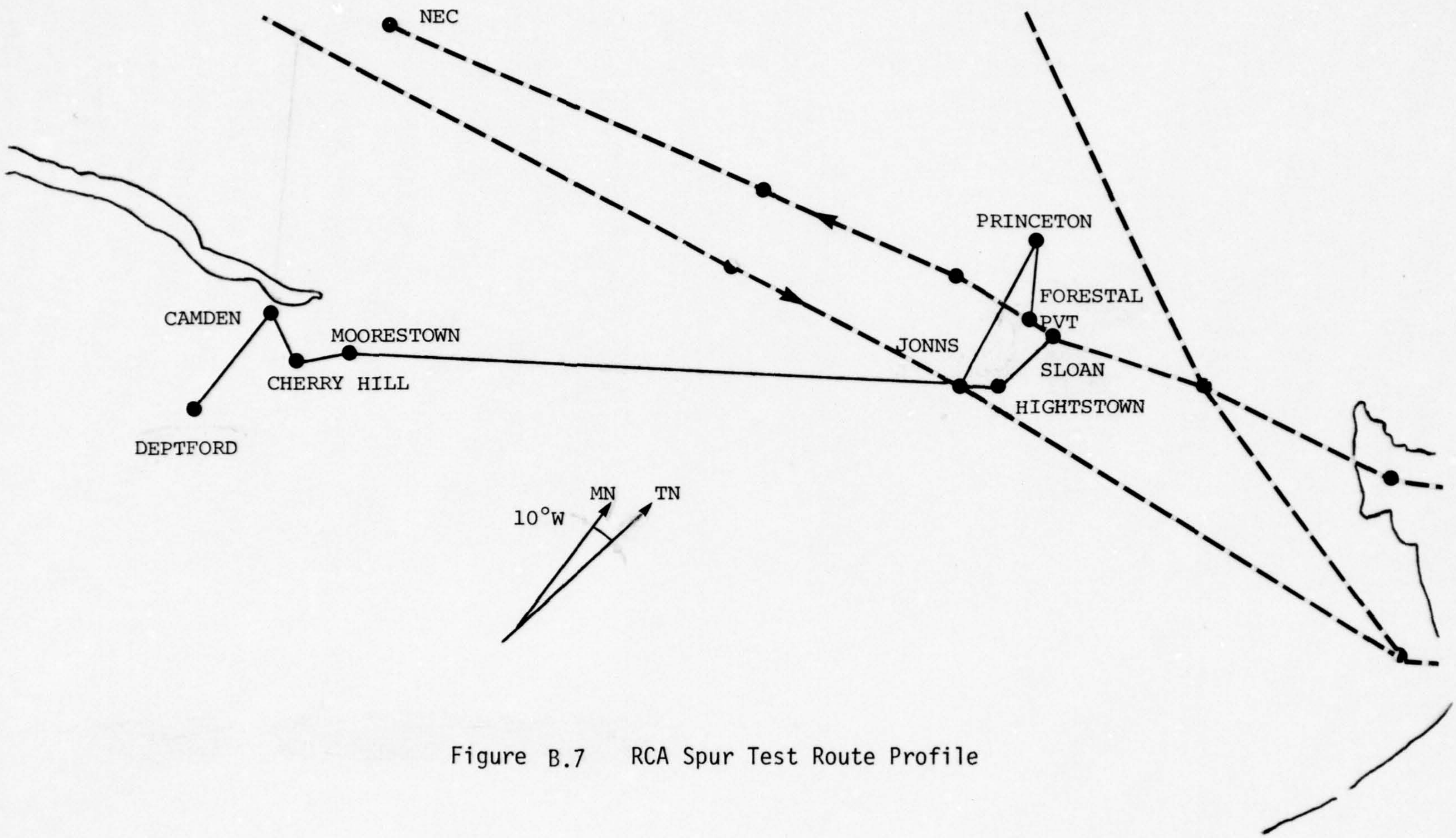


Figure B.7 RCA Spur Test Route Profile

Table B.11 RCA (Spur Route Scenario)

ROUTE	AIRSPACE Enroute Segments	AIRSPACE PISA	ATD (nm)	HOURS
DEPTFORD - CAMDEN - CHERRY HILL - MOORESTOWN - JONNS - HIGHTSTOWN - SLOAN FORESTAL PVT - PRINCETON	8	7	57.5	0.98
PRINCETON - JONNS - MOORESTOWN - CHERRY HILL - CAMDEN - DEPTFORD	5	4	48.5	0.91
DEPTFORD - CAMDEN - CHERRY HILL - MOORESTOWN - JONNS - HIGHTSTOWN - SLOAN - FORESTAL PVT - PRINCETON	8	6	57.5	0.98
TOTAL	21	17	163 nm	2.87 hours

Table B.12 RCA Spur Test Route Definition

WAYPOINT NAME	NUMBER	MEA (feet MSL)	LATITUDE (deg.-min.)	LONGITUDE (deg.-min.)	TRUE COURSE (deg.)	MAG. VAR. (deg.)	ALONGTRACK DISTANCE (nm)
*DEPTFORD	1	2000'	39 50.56'	75 06.14'	———	10 W	———
*CAMDEN	2	2000'	39 56.12'	75 08.82'	399.72	10 W	5.93
*CHERRY HILL	3	2000'	39 56.36'	75 00.59'	87.78	10 W	6.31
*MOORESTOWN	4	2000'	39 58.49'	74 54.47'	65.55	10 W	5.15
JONNS	5	2000'	40 15.87'	74 36.22'	38.66	10 W	22.2
*HIGHTSTOWN	6	2000'	40 17.10'	74 33.79'	56.42	10 W	2.22
SLOAN	7	2000'	40 20.62'	74 34.10'	356.15	10 W	3.52
*FORESTAL PVT.	8	2000'	40 20.50'	74 37.30'	260.45	10 W	1.45
*PRINCETON	9	2000'	40 23.80'	74 40.20'	319.72	10 W	4.75
JONNS	10	2000'	40 15.87'	74 36.22'	160.47	10 W	8.63
*MOORESTOWN	11	2000'	39 58.49'	74 54.47'	218.86	10 W	22.2
*CHERRY HILL	12	2000'	39 56.36'	75 00.59'	245.61	10 W	5.15
*CAMDEN	13	2000'	39 56.12'	75 08.82'	267.87	10 W	5.31
*DEPTFORD	14	2000'	39 50.56'	75 06.14'	159.69	10 W	5.93
*CAMDEN	15	2000'	39 56.12'	75 08.82'	339.71	10 W	5.92
*CHERRY HILL	16	2000'	39 56.36'	75 00.59'	87.77	10 W	6.31
*MOORESTOWN	17	2000'	39 58.49'	74 54.47'	65.55	10 W	5.15
JONNS	18	2000'	40 15.87'	74 36.22'	38.66	10 W	22.2
*HIGHTSTOWN	19	2000'	40 17.10'	74 33.79'	56.42	10 W	2.22
SLOAN	20	2000'	40 20.26'	74 34.10'	356.15	10 W	3.52
*FORESTAL PVT.	21	2000'	40 20.50'	74 37.30'	260.45	10 W	1.45
*PRINCETON	22	2000'	40 23.80'	74 40.20'	319.72	10 W	4.75

*Executed Approaches for These Waypoints Only

B.1.2 NAFEC System Accuracy Test Routes

The NAFEC System Accuracy Testing provided supplemental enroute, transition, terminal maneuvering and final approach data using both the HH52 and the HH3 aircraft. This additional data augments the data previously acquired solely on the HH52 during previous testing of the AN/ARN-133 and during the previous tests which utilized the prototype Loran-C navigator (TDL-424). The latter data was reported in "An Operational Flight Test Evaluation of a Loran-C Navigator" (Report No. CG-D-9-77). It is considered that the acquisition of accuracy and operational data from the AN/ARN-133 in an HH3 aircraft is necessary to substantiate that the installation effects for at least these two aircraft types are negligible. The NAFEC tests utilized the same route profiles that were flown previously using the AN/ARN-133 and TDL-424 navigators (Figure B.8). The data base recorded during the NAFEC tests supplements the prototype data collected for demonstration of compliance with the area navigation requirements of FAA Advisory Circular 90-45A, "Approval of Area Navigation Systems in the U.S. National Airspace System".

The basic NAFEC testing consisted of enroute, terminal and final approach data collection on both the HH52 and HH3 helicopters. The NAFEC test program is summarized in Figure B.9. The sequence of data collection was to initially fly the HH52 equipped with the AN/ARN-133 in the non-updated mode for comparison with prototype TDL-424 results. These tests were performed in July 1978 using the 9930 chain which was also used during the November 1976 prototype evaluation. Carolina Beach was the master with Nantucket and Dana as secondaries. The next set of NAFEC System Accuracy tests also used the HH52, but updating the Loran-C navigator at the Cape May helipad prior to departure. This data provides the effect on system accuracy for updated vs non-updated modes with the same installation, routes and crew. Finally, the HH3 NAFEC System Accuracy tests were flown in November 1978. At this time, the 9960 Loran-C chain was operational. Consequently, the HH3 data is not only on a new crew and aircraft, but also on the new chain. Seneca was the master with Carolina Beach and Nantucket as secondaries for this chain. The chain geometry was significantly different in this configuration (refer to Figures A.7 and A.8 for a comparison of 9930 to 9960 geometry). The HH3 tests were flown non-updated. This data can, therefore, be compared with the HH52 prototype and production non-updated test results for relative accuracy. The effects of the larger and faster helicopter can not, however, be separated from the effects of the new chain.

The basic HH3 tests consisted of a single circuit of the entire NAS route (Figure B.8) which required two hours. Figure B.9 presented the NAFEC flight test matrix from a data sample size viewpoint. The HH3 NAS tests collected 200 nm of accuracy data including enroute, terminal, and approach segments. On each NAS test route a total of two STARs, two non-precision approaches, two SIDs and two independent enroute segments were flown. The two non-precision approaches on each NAS route were to the

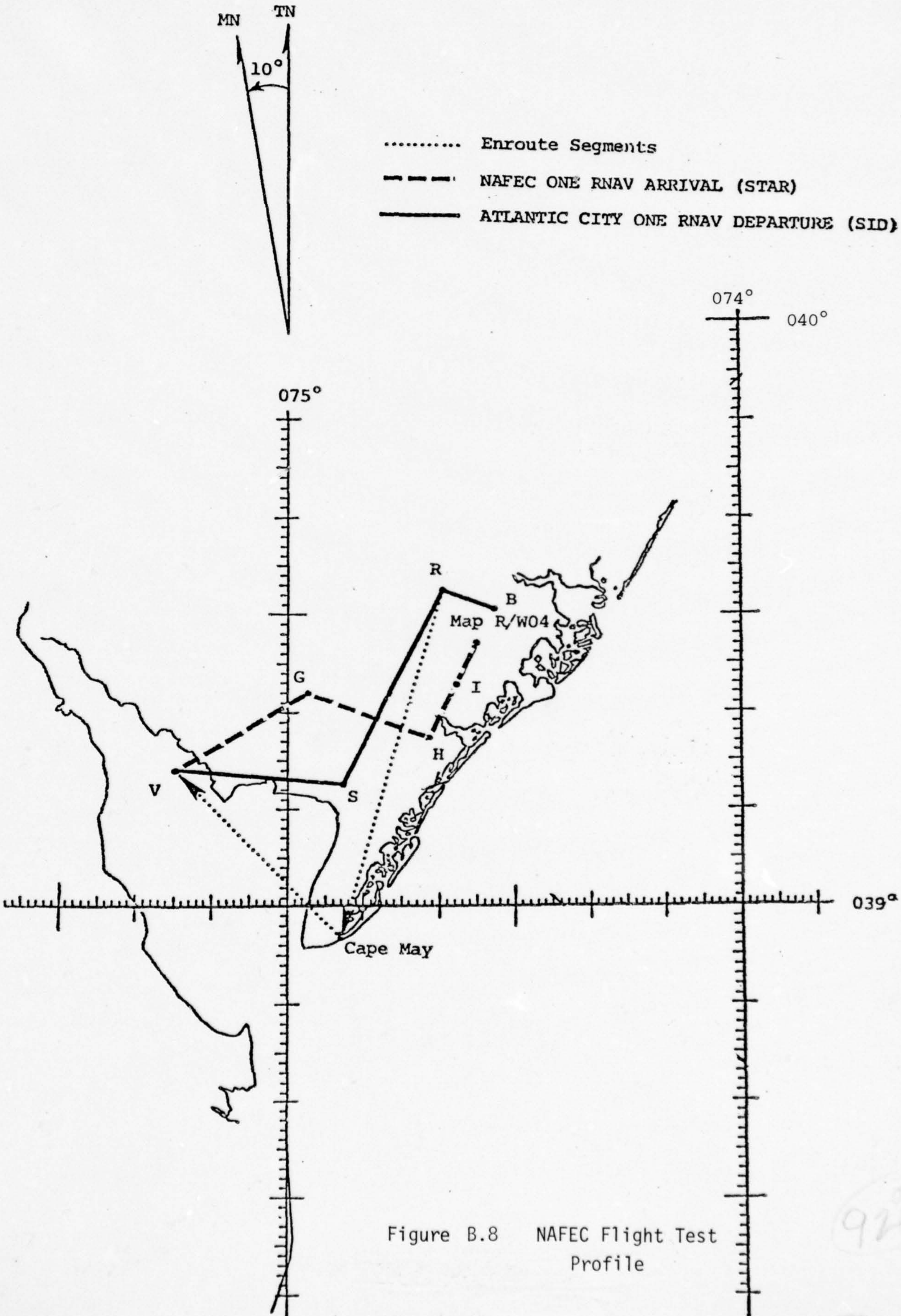


Figure B.8 NAFEC Flight Test Profile

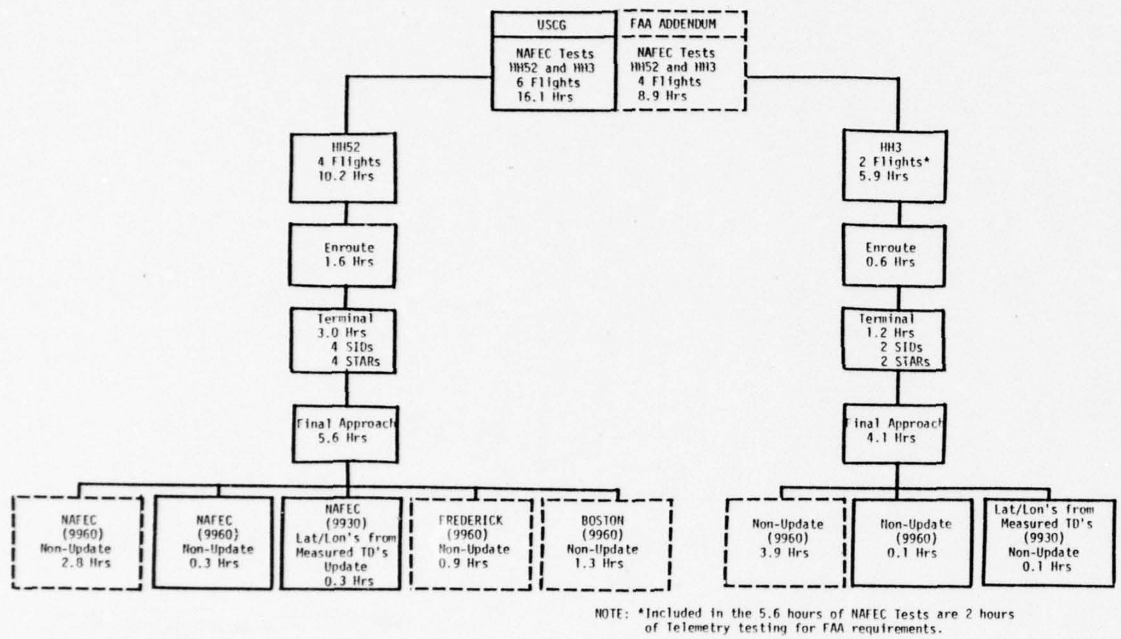


Figure B.9 NAFEC System Accuracy Test Program

same runway at the NAFEC airport (rwy 04), but were flown utilizing different waypoint coordinates. The first approach used waypoint coordinates that were measured in time differences by the prototype Loran-C navigator (TDL-424) and converted to lat/lon equivalents. During the tests reported in USCG Report No. CG-D-9-77, the first approach of each NAS test route was flown using the above flight procedure. Flying the first approach during the production tests utilizing these same coordinates was planned to determine long term signal repeatability and Loran-C receiver variations. The second non-precision approach on each NAS test route utilized standard charted lat/lon coordinates without updating the Loran-C navigator. The overview of the selected NAS flight profiles was shown in Figure B.8.

These profiles include two enroute segments of 24 and 38 nautical miles in length. The enroute data was obtained between Cape May and Victor (V) waypoint and also between the NAFEC terminal area waypoint Romeo (R) and Cape May. These enroute segments are shown as dotted lines on Figure B.8. The terminal area route segments evaluated during the NAS testing were derived from routes developed for the New York-Kennedy terminal area. The operational SID and STAR routes for southwest traffic flow on runway 22 at JFK were rotated and overlayed on runway 04 at NAFEC for the purposes of this test program.

Table B.13 summarizes the NAFEC flight test route, for each type of airspace (terminal, enroute and approach), along track distance between each segment and the number of times these were flown by the HH3 and HH52 aircraft, respectively. Table B.14 presents the detailed waypoint location information (latitude/longitude), course information (true and magnetic course), and the appropriate segment lengths for each of the NAFEC routes.

The HH52 NAFEC accuracy testing included 123.0 nm of enroute testing, 231.4 nm of terminal maneuvering and 44.0 nm of final approach data. The enroute and terminal data was taken over the same routes as the HH3 data. The final approach data included not only NAFEC approaches, which were tracked by EAIR, but also a qualitative comparison of the approach accuracy at NAFEC with data acquired at Frederick, Maryland and Boston, Massachusetts. The following paragraphs describe the final approach data collection in detail.

The NAFEC final approach data base consisted of six hours of testing; one hour to each end of runways 04/22, 08/26, 13/31 at NAFEC. These runways are pictured on the Jeppesen Approach Chart, Figure B.10. Approaches using both the HH52 and the HH3 began approximately 4.0 nm off the end of each runway. A conventional downwind, base and final approach pattern were flown. The same number of approaches were flown to each runway by each aircraft to balance the statistical results for all approach directions.

Table B.13 NAFEC Flight Test Sample Size

AIRSPACE	SEGMENT	SEGMENT LENGTH (nm)	TOTAL TIMES FLOWN		TOTAL SEGMENT LENGTH (nm)
			H-3	H-52	
ENROUTE (lat/lon without update)	Cape May-Victor	24.3	1	2	72.9
	Romeo-Cape May	37.2	1	2	111.6
TERMINAL (lat/lon without update)	NAFEC-Bravo	3.5	2	4	21.0
	Bravo-Romeo	5.9	2	4	35.4
	Romeo-Sierra	22.4	1	2	67.2
	Sierra-Victor	17.1	1	2	51.3
	Victor-Golf	15.7	2	4	94.2
	Golf-Hotel	13.0	2	4	78.0
APPROACH (lat/lon with and without update)	Hotel-India	6.0	1	2	18.0
	India-MAP (R/W 04)	5.0	1	2	15.0
APPROACH (measured time differences)	Hotel-India	6.0	1	2	18.0
	India-MAP (R/W 04)	5.0	1	2	15.0
TOTALS (segments)			16	32	597.6

NOTE:
1. The total distance required to fly one complete NAFEC test profile is: 199.2 nm
2. The H-3 test helicopter flew the NAFEC test profile once: 199.2 nm (1 flight)
3. The H-52 test helicopter flew the NAFEC test profile twice: 398.4 nm (4 flight)

Table B.14 NAS Pattern Waypoint Definition

WAYPOINT	LATITUDE (N)	LONGITUDE (W)	TRUE COURSE (deg.)	MAGNETIC COURSE (deg)	SEGMENT LENGTH (nm)
Cape May (CM)	038° 56.63'	074° 53.08'	—	—	—
Victor (V)	039° 14.00'	075° 15.00'	315.5	325.5	24.3
Golf (G)	039° 22.00'	074° 57.50'	059.4	069.4	15.7
Hotel (H)	039° 17.23'	074° 41.83'	111.3	121.3	13.0
India (I)	039° 22.53'	074° 38.18'	028.0	038.0	6.0
MAP (R/W 04)	039° 26.95'	074° 35.15'	028.0	038.0	5.0
Bravo (B)	039° 30.05'	074° 33.01'	028.0	038.0	3.5
Romeo (R)	039° 32.50'	074° 40.00'	284.4	294.4	5.9
Sierra (S)	039° 12.50'	074° 53.00'	206.8	216.8	22.4
S-V	—	—	275.1	285.1	17.1
R-CM	—	—	195.8	205.8	37.2
Hotel (H)*	039° 17.22'	074° 41.11'	110.6	120.6	13.6
India (I)*	039° 22.43'	074° 37.57'	027.7	037.7	5.9
MAP (R/W04)*	039° 26.85'	074° 34.58'	027.6	037.6	5.0

/NOTE/*The lat/lon of these waypoints were measured by the Loran-C TDL-424 Navigator in Loran-C time difference coordinates with the 9930 chain and later converted by the same TDL-424 to lat/lon coordinates.

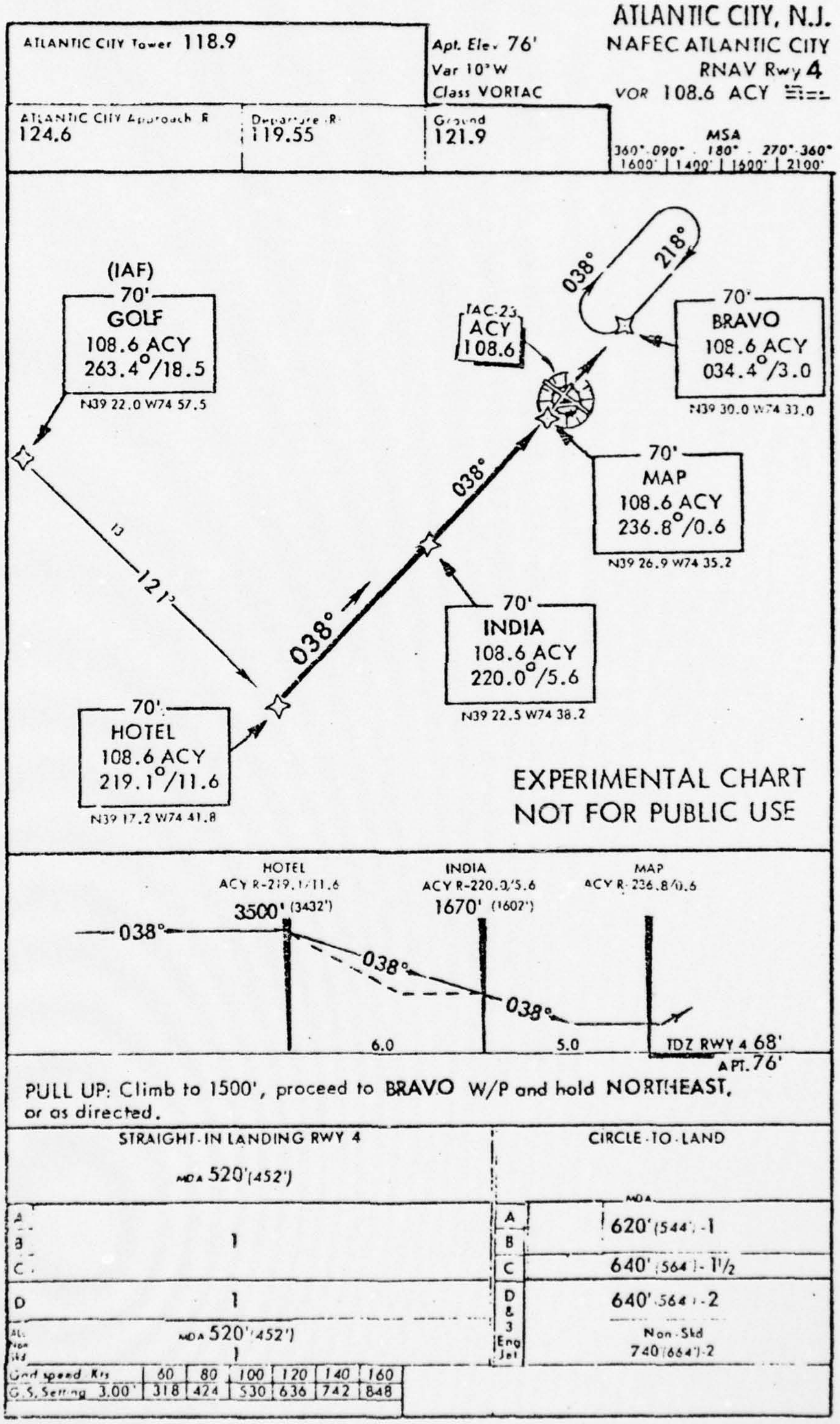


Figure B.10 Approach Plate Runway 04 at NAFEC

Figure B.11 illustrates the geometry of each approach data set in the form of a generalized runway/flight pattern configuration. The aircraft departed, for example, on runway 04. Upon reaching sufficient altitude the aircraft flew a crosswind leg to intercept the pattern altitude and the downwind course. The downwind leg was terminated at the base leg turn waypoint (BLTP) and the base was flown to the missed approach point (MAP), a missed approach was executed and the pattern repeated. This profile continued until three approaches were made to the end of each of the six runways. Both precision tracking radar and Loran-C airborne data were recorded continuously during each of the total 18 approaches for each aircraft. Accuracy statistics in the form of mean and two-sigma crosstrack error were computed for each of the approach courses as well as in aggregate for all approach courses combined.

Table B.15 provides base leg turn waypoint (BLTP) and approach point (AP) waypoint information appropriate for each runway at NAFEC. These NAFEC approaches were performed to determine the effect of the Loran-C bias error which was discovered during the prototype testing. The prototype data was collected using only runway 04. In order to estimate the Loran-C approach accuracy (bias) at locations other than NAFEC, additional data was collected at Frederick, Maryland (Figure B.12) and Boston, Massachusetts (Figure B.13). The HH52 aircraft flew these tests using the 9960 Loran-C chain. Since no precision tracking radar was available, data for these operational approaches was collected in two ways. First, an ILS equipped runway was used at each location. Initially, multiple ILS approaches were flown while digitally recording airborne Loran-C position information and observing the localizer needle deflection. In this way, areas where the needle was centered can be used to obtain an estimate of Loran-C bias errors. Subsequent to the ILS approaches, several Loran-C approaches were made with visual observation as to the magnitude of the bias error. These qualitative estimates were compared with the EAIR approach accuracy statistics. The second method was similar to the first except that visual approaches were flown where ILS was not available.

4.2.3 Offshore Test Profiles

The Offshore test routes were unique to the specific objectives in these five basic test areas:

1) Deep Probe Overwater Tests

2) Coastline Signal Anomaly Tests

3) Ship/Helo Rendezvous Tests

4) Oil Rig Tests

5) Search and Rescue Tests

Of these five Offshore test areas, numbers 1), 2) and 5) were performed in the Atlantic Ocean offshore from Atlantic City, New Jersey. Tests 3) and 4) were performed in the Gulf of Mexico. The deep probe tests were performed using the HH3 aircraft due to its range and twin engine capabilities. The remainder of the offshore

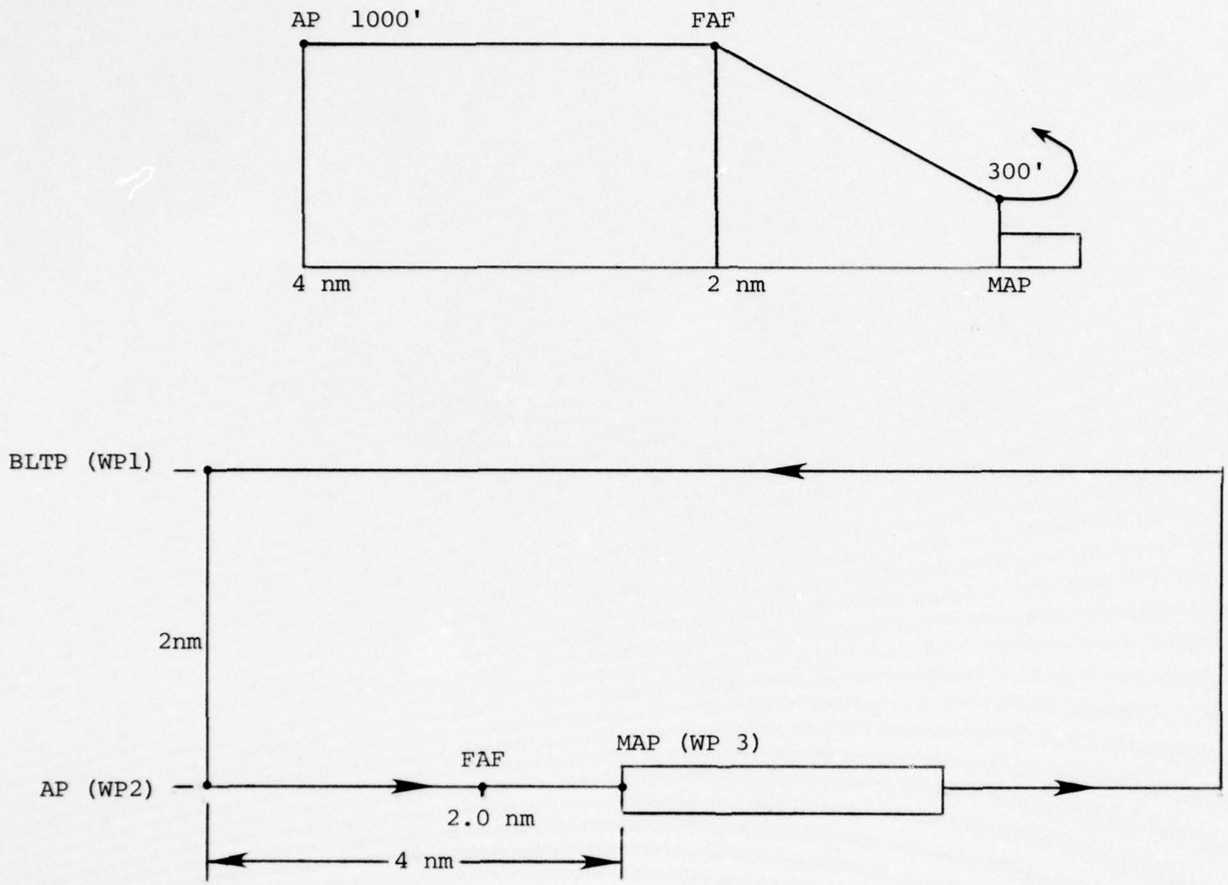


Figure B.11 Generalized Runway Flight Pattern Configuration For Final Approach Tests

(186)

Table B.15 NAFEC Final Approach Test Waypoint Information

Runway	Approaches	Waypoint	Latitude	Longitude
04	3	BLTP	39° 24.39'	74° 39.83'
		AP	39° 23.46'	74° 37.54'
		MAP	39° 26.99'	74° 35.12'
22	3	BLTP	39° 30.41'	74° 29.75'
		AP	39° 31.37'	74° 32.02'
		MAP	39° 27.87'	74° 34.52'
08	3	BLTP	39° 27.15'	74° 40.80'
		AP	39° 25.38'	74° 39.91'
		MAP	39° 27.01'	74° 35.18'
26	3	BLTP	39° 27.17'	74° 28.38'
		AP	39° 28.99'	74° 29.43'
		MAP	39° 27.36'	74° 34.16'
13	3	BLTP	39° 31.49'	74° 38.84'
		AP	39° 29.73'	74° 40.06'
		MAP	39° 27.85'	74° 35.49'
31	3	BLTP	39° 23.44'	74° 30.28'
		AP	39° 25.19'	74° 29.04'
		MAP	39° 27.08'	74° 33.61'

Jeppesen Approach Chart JUN 16-78 (13-1)

FREDERICK, MD.

FREDERICK MUN

VOR Rwy 23

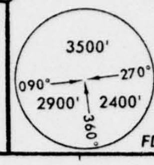
VOR 109.0 FDK

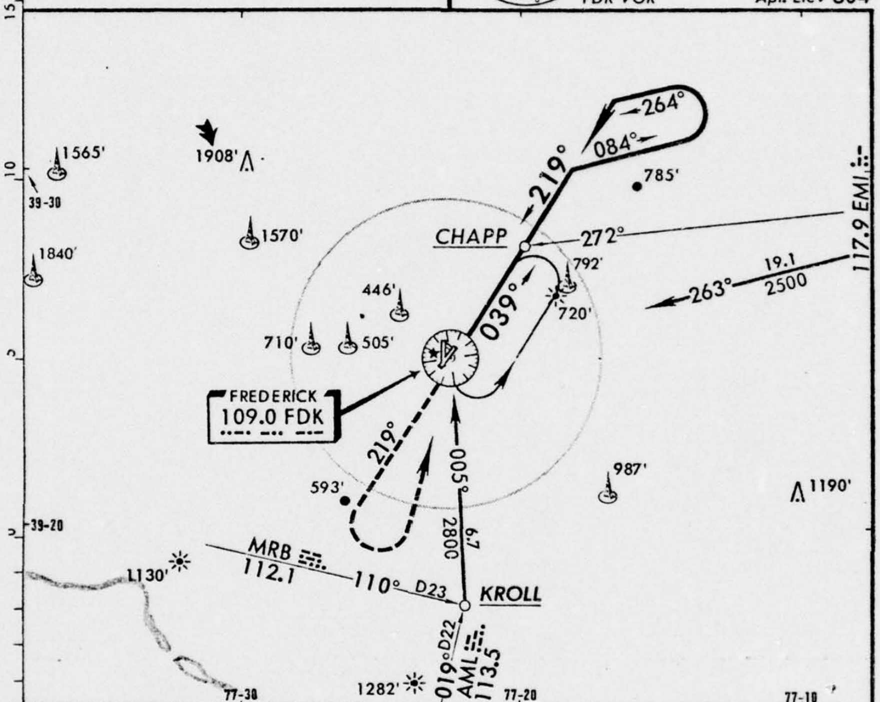
Class BVOR

Apt. Elev 304'

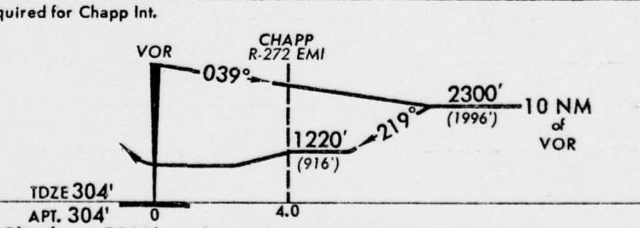
BALTIMORE Approach (R) 119.0

Use Martinsburg altimeter setting.





NOTE: Dual VOR required for Chapp Int.



MISSED APPROACH: Climb to 2300' outbound on FDK VOR R-219, LEFT turn direct to FDK VOR and hold NORTHEAST, LEFT turns.

	STRAIGHT-IN LANDING RWY 23			CIRCLE-TO-LAND	
	MDA 1100'(796') With Chapp	MDA 1220'(916') Without Chapp		With Chapp MDA	Without Chapp MDA
A	1	1¼	A	1100'(796')-1	1220'(916')-1¼
B	1¼	1½	B	1100'(796')-1¼	1220'(916')-1½
C	1½	1¾	C	1100'(796')-1½	1220'(916')-1¾
D	1¾	2	D	1180'(876')-2	1220'(916')-2

Gnd speed-Kts	60	80	100	120	140	160
MAP at VOR						

CHANGES: FAF symbol deleted at Chapp.

Figure B.12 Frederick Approach Plate

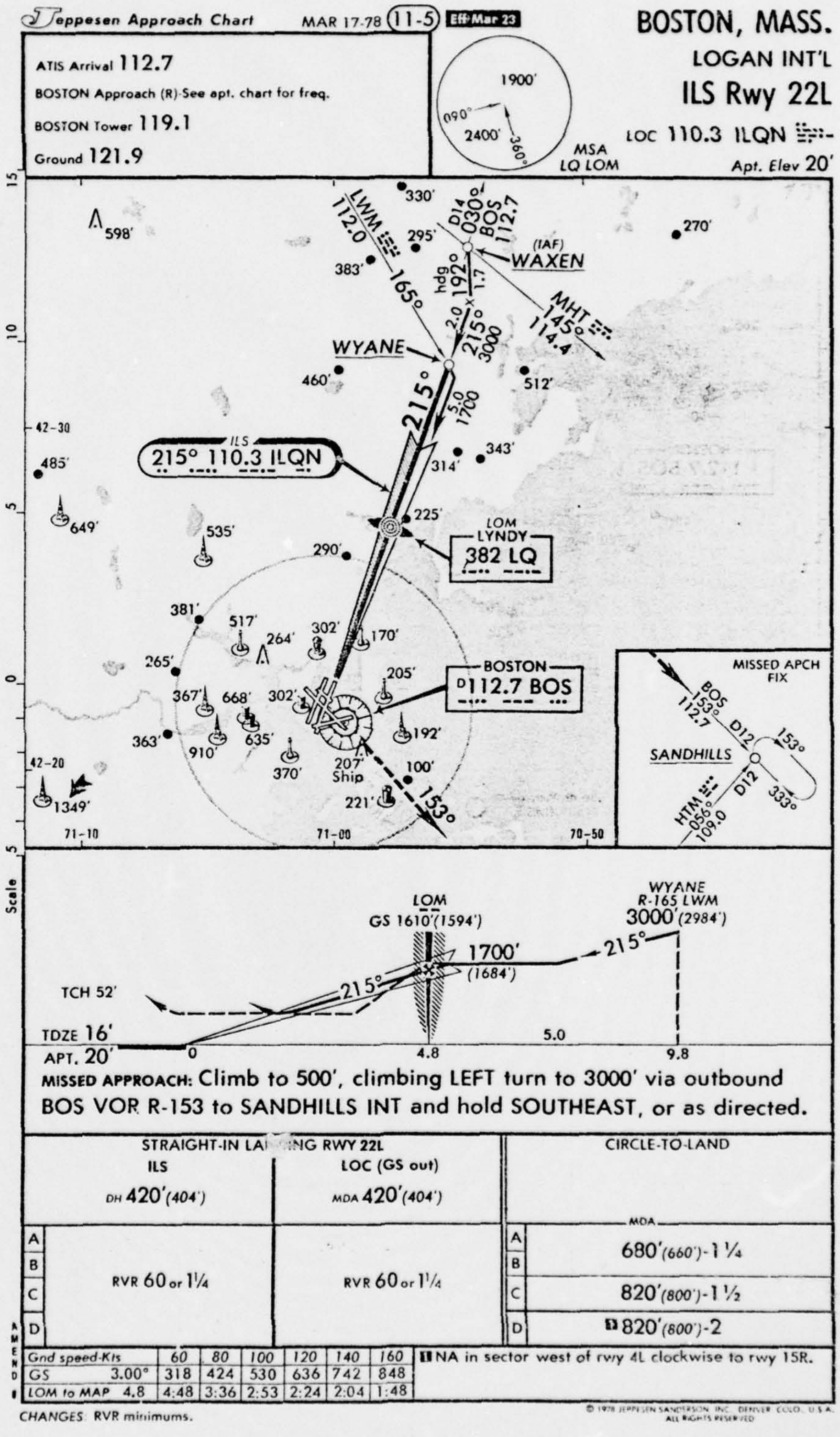


Figure B.13 Boston Approach Plate

tests were performed in the HH52 aircraft. This section provides the detailed test routing information along with pilot procedures and waypoint location information.

A. DEEP PROBE OVERWATER TEST

One of the test objectives in this USCG Loran-C Flight Test Plan was to demonstrate operation of the Loran-C Navigator during long range overwater missions. A second objective was to demonstrate the accuracy and operational ATC interface problems in the overland/overwater transition. Three flights, each of approximately 4.0 hours duration, were planned for these purposes. An HH3 aircraft based at Otis AFB on Cape Cod was the dedicated aircraft for these tests. The deep probe test consisted essentially of flying overwater to a maximum of 200 nm from the coast. The test aircraft departed and returned from the NAFEC airport in Atlantic City, New Jersey.

Figure B.14 shows the test profile of the deep probe overwater test. Basically, the shape of the test pattern was that of a parallelogram with dimensions of approximately 200 nm by 15 nm. The test pattern extended from the coast and over the Atlantic Ocean in a southeasterly direction. At 200 nm from the NAFEC airport the closest land is 135 nm to the northwest (the Long Island, New York coastline).

Figure B.15 presents an expanded view of the test profile. The test flight was initiated from the NAFEC airport. Takeoff was followed by a climb direct-to-Bravo (B) waypoint. The outbound leg (200 nm) over the Atlantic Ocean began at Bravo waypoint and ended at Charlie (C) waypoint. At the conclusion of the outbound leg (200 nm from the NAFEC airport) the aircraft transitioned southbound for 14.8 nm to waypoint Delta (D), still at 200 nm from the NAFEC airport. The aircraft then proceeded inbound to waypoint Hotel (H) which was 200 nm from Delta waypoint. At Hotel the aircraft initiated a non-precision approach to NAFEC airport runway 04 and landed. Total alongtrack distance for the test flight was approximately 430 nm. At an average airspeed of 110 nm per hour the total flight time would be 4 hours.

The NAFEC EAIR radar tracked the aircraft during the initial and final portions of the flight. It was estimated that the NAFEC radar could accurately track the test aircraft during the first and last 100 nm of the deep probe over the Atlantic Ocean. The test aircraft climbed and maintained a minimum altitude of 9000 feet (MSL) in order to insure 100 nm of offshore radar coverage.

Table B.16 defines the deep probe test scenario in detail. Waypoint location in latitude and longitude coordinates are provided for each of the waypoints. In addition, both true and magnetic course and alongtrack distance are provided for each route segment. Figure B.16 is the approach plate for the non-precision approach to NAFEC airport runway 04.

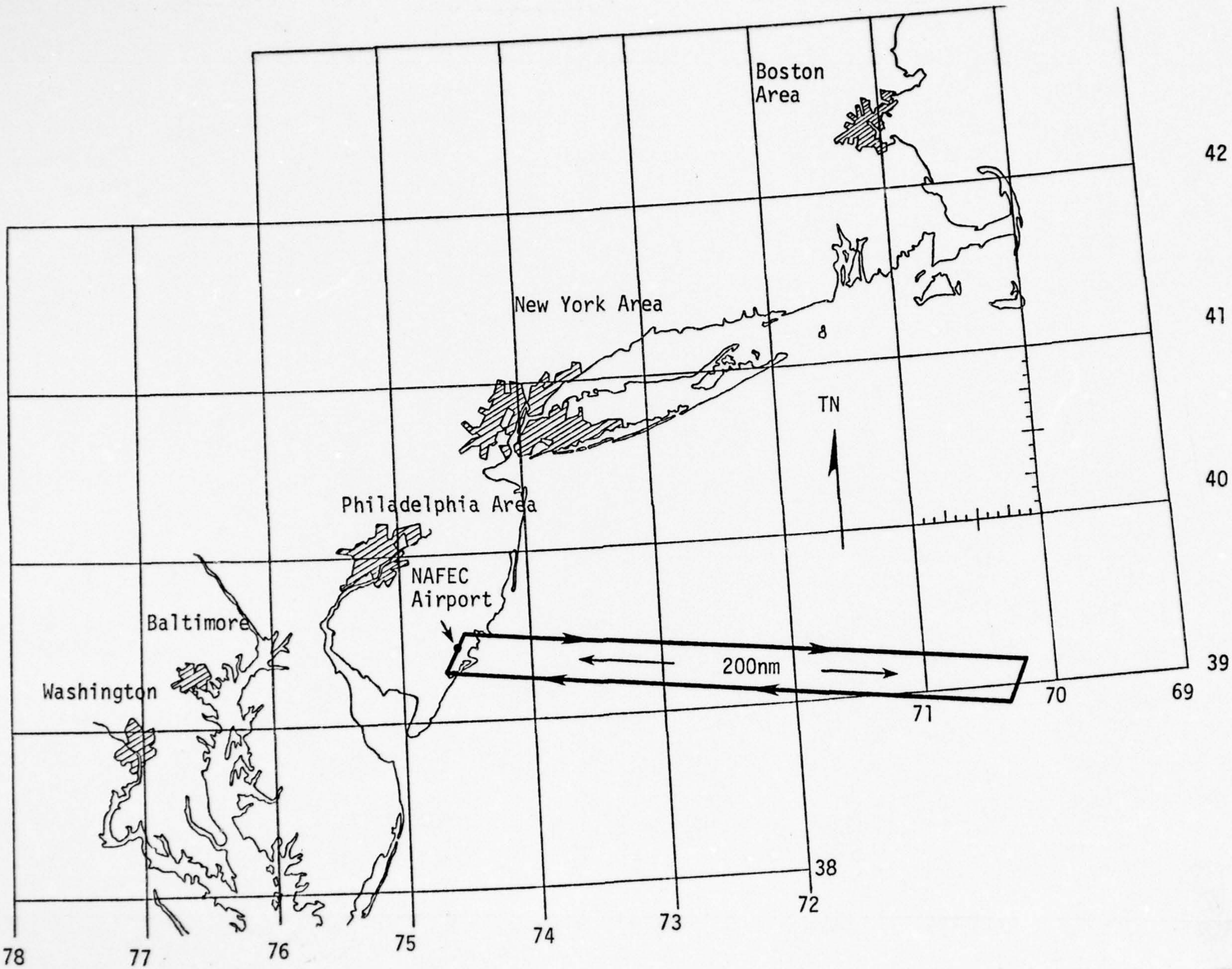
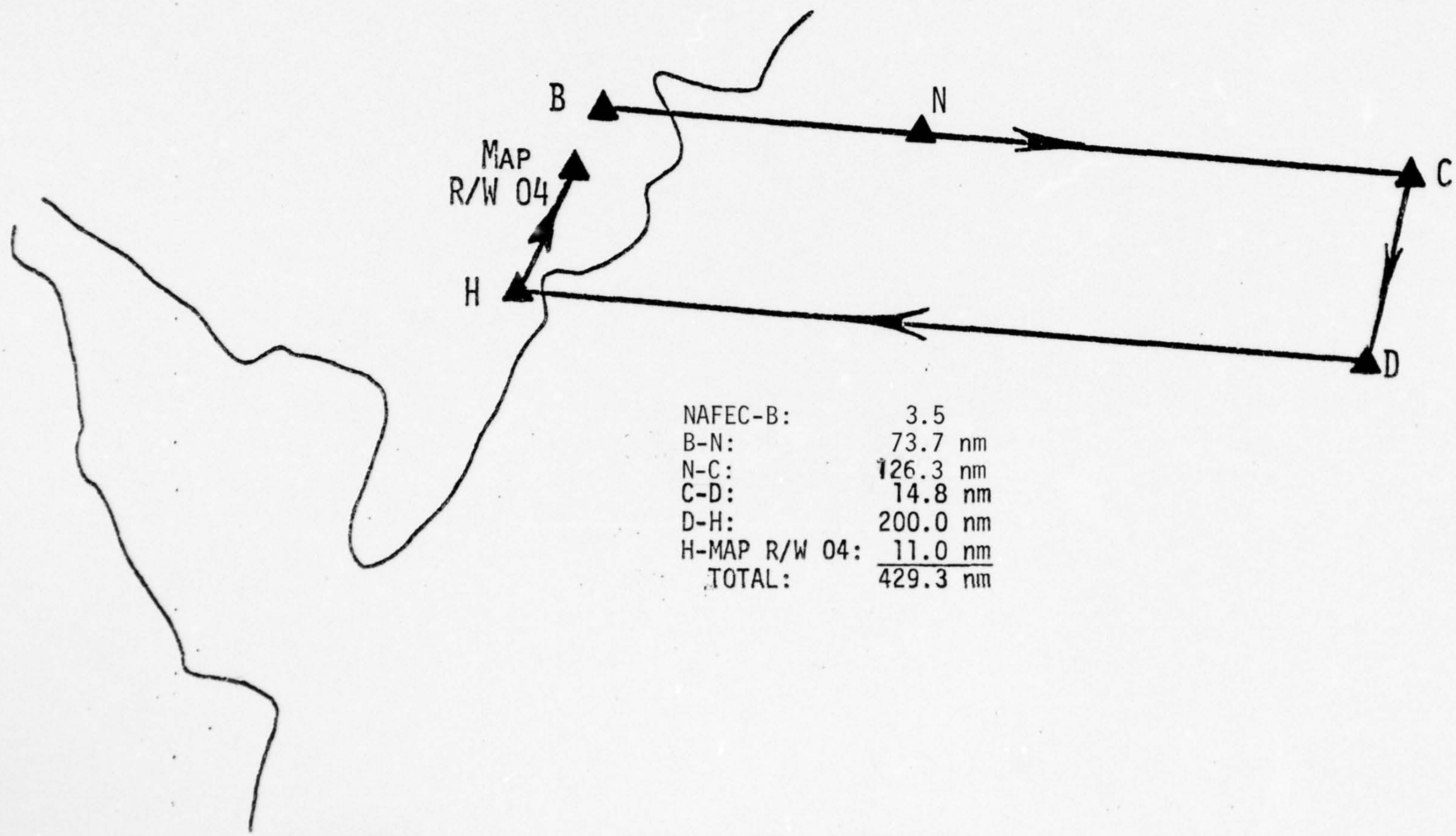


Figure B.14 Deep Probe Overwater Test Profile Geography

(191)



NAFEC-B:	3.5
B-N:	73.7 nm
N-C:	126.3 nm
C-D:	14.8 nm
D-H:	200.0 nm
H-MAP R/W 04:	11.0 nm
TOTAL:	429.3 nm

Figure B.15 Expanded Deep Probe Overwater Test Profile

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Table B.16 Deep Probe Overwater Test Scenario

WAYPOINT	LATITUDE Deg. & Min.	LONGITUDE Deg. & Min.	TRUE COURSE (Deg.)	MAGNETIC COURSE (Deg.)	MAGNETIC VARIATION (Deg.)	ALONGTRACK DISTANCE (NM)	REMARKS
NAFEC (Airport)							Take-off
BRAVO (B)	39° N 30.05	74° W 33.01	028.0	038.0	10	3.5	Departure
CHARLIE (C)	39° N 07.53	70° W 16.04	095.0	108.0	14	200.0	Enroute
DELTA (D)	38° N 55.06	70° W 25.40	210.3	224.0	14	14.8	Enroute
HOTEL (H)	39° N 17.23	74° W 41.83	277.7	287.7	10	200.0	Enroute
MAP (R/W 04)	39° N 26.95	74° W 35.15	028.0	038.0	10	11.0	Approach-Land

NOTE:

1. 430 nm - Total Alongtrack Distance
2. Estimated Flight Time is 4 Hours @ 110 nm Per Hour

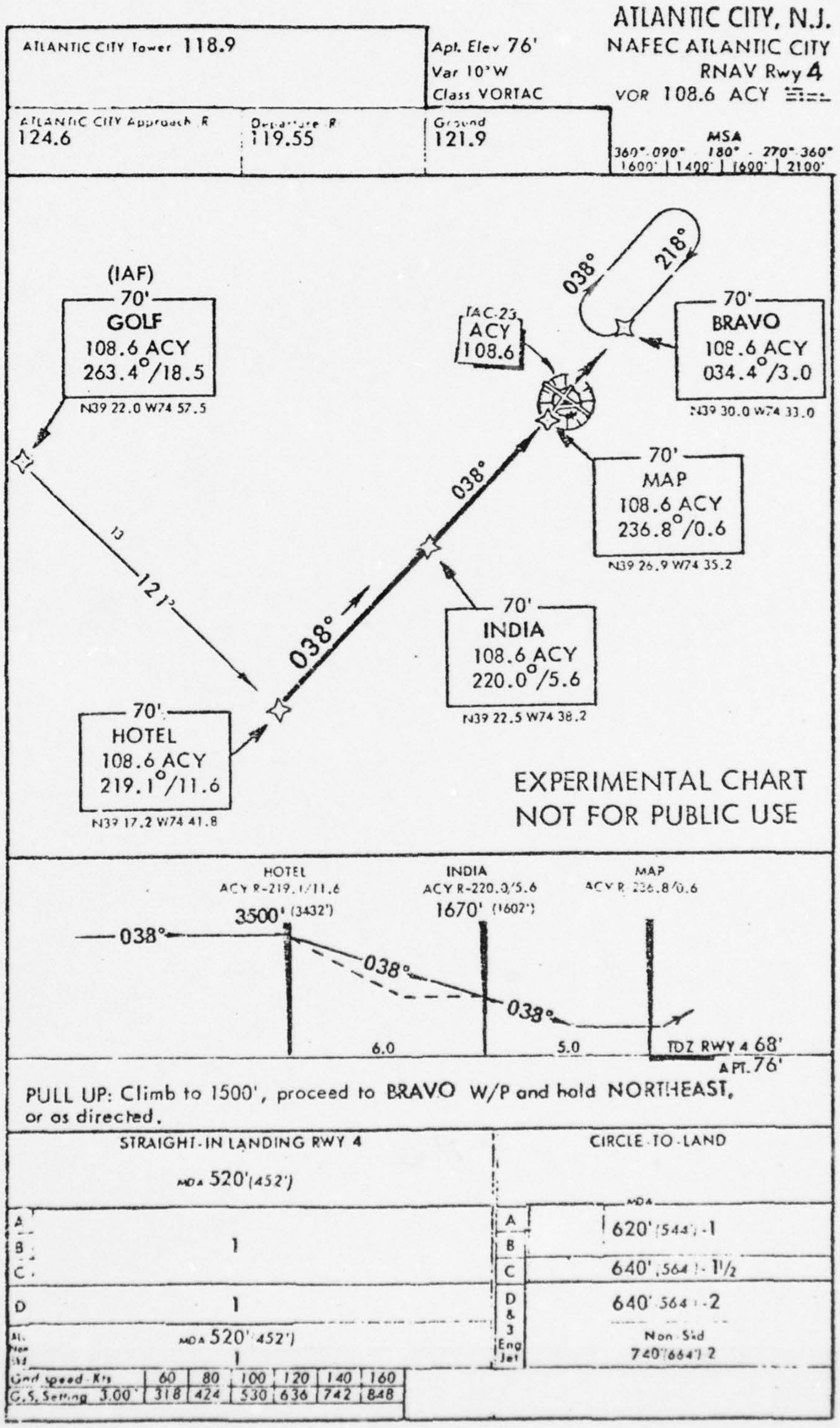

Figure B.16 Approach Plate Runway 04 at NAFEC

B. COASTLINE ANOMALY TESTS

This test was structured to obtain data on the postulated Loran-C overland/overwater transition signal anomaly which could impact Loran-C usability. The test involved two flights in the HH52 aircraft, one at dawn and one at dusk, at an 80 knot cruise speed covering 448 nm of along track distance and 128 nm of coastline for a total of 6.0 hours. The dusk test originated at NAFEC, whereas the dawn test originated from Cape May as a matter of convenience. As illustrated in Figure B.17 the dusk test began on the coast approximately 6 nm southeast of NAFEC (Commence Search Point - CSP) at an altitude of 1000 feet MSL. The HH52 then proceeded outbound 16 nm along the coast utilizing the creeping line search pattern (CS) capability of the AN/ARN-133 Loran-C navigator. The 16 nm segment is illustrated in Figure B.17 by the solid line connecting CSP A and CSP B. When the HH52 completed the programmed 16 nm CS pattern, it was in position to intercept CSP B (Figure B.17). At this point the HH52 climbed to 1500 feet MSL and the pilot programmed the navigator with a 32 nm CS pattern to CSP C. Midway through this segment the HH52 climbed to 2000 feet MSL. When the HH52 had completed the 32 nm CS pattern segment (CSP B to CSP C), it climbed to 2500 feet MSL and the pilot programmed the final 16 nm CS pattern returning to CSP A. This pattern returned the HH52 to a position approximately 6 nm southeast of NAFEC.

Also illustrated in Figure B.17, the dawn test began on the coast approximately 15.5 nm north of Cape May at an altitude of 2500 feet MSL. At a point 16 nm DTW CSP B, HH52 descended to 2000 feet MSL. An altitude of 1500 feet MSL was maintained to a point 16 nm DTW CSP A, at which point the HH52 descended to 1000 feet MSL for the remainder of the test.

Table B.17 defines the dawn and dusk coastline signal anomaly test data input identifying waypoint lat/lon, flight altitude and creeping line search pattern input data.

Six hours of data were gathered with both the onboard data recorder and with EAIR ground tracking radar at NAFEC.

C. SHIP/HELO RENDEZVOUS TESTING

The ship/helo rendezvous testing was comprised of three basic tests. Figure B.18 presents the profiles flown on each of the three tests and Table B.18 summarizes the test procedures. Tests 1 and 2 utilized the USCG HH52 procedural rendezvous and approach pattern (Beep-to-hover) in conjunction with waypoints defined using the Loran-C navigator. The Test 1 profile required only one waypoint created by the Display Hold key while over the ship. The current USCG rendezvous procedures were used to establish the approach leg. The Test 2 profile was defined with a Display Hold waypoint and a ρ,θ waypoint from the Display Hold waypoint establishing the approach leg to the ship. The purpose of tests 1 and 2 was to investigate the pilot workload using the USCG procedural rendezvous pattern in conjunction with Loran-C. In addition, these tests will be used to show that these procedures can be simplified when the approach leg is defined by Loran-C waypoints. Tests 1 and 2 were expected to show minimum accuracy, high workload and improved accuracy, high workload, respectively.

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AIRBORNE EVALUATION OF THE PRODUCTION AN/ARN-133 LORAN-C NAVIGA--ETC(U)
JUL 79 R J ADAMS, J B MCKINLE DOT-FA75WA-3662
UNCLASSIFIED USCG-D-32-79 NL

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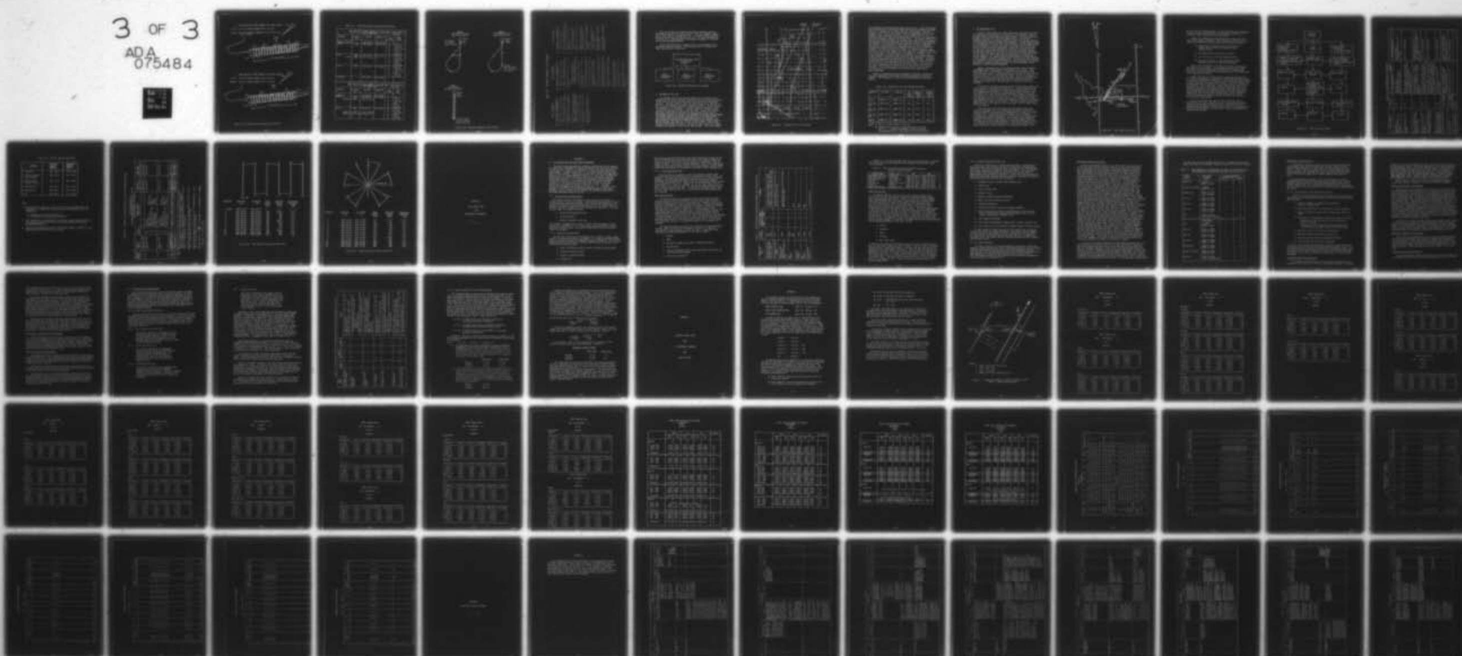

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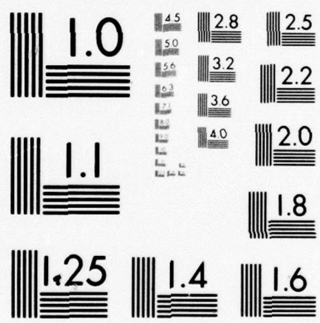


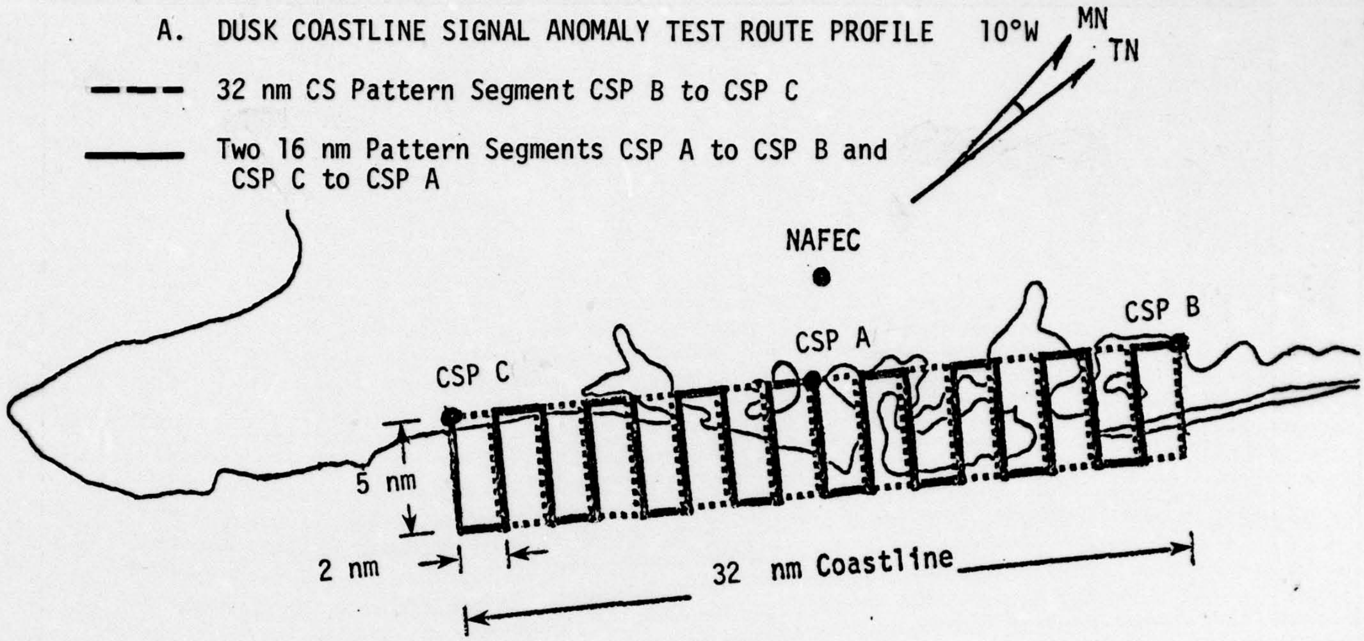
MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU

A. DUSK COASTLINE SIGNAL ANOMALY TEST ROUTE PROFILE

32 nm CS Pattern Segment CSP B to CSP C

Two 16 nm Pattern Segments CSP A to CSP B and CSP C to CSP A



B. DAWN COASTLINE SIGNAL ANOMALY TEST ROUTE PROFILE

32 nm CS Pattern Segment CSP B to CSP A

32 nm CS Pattern Segment CSP A to CSP B

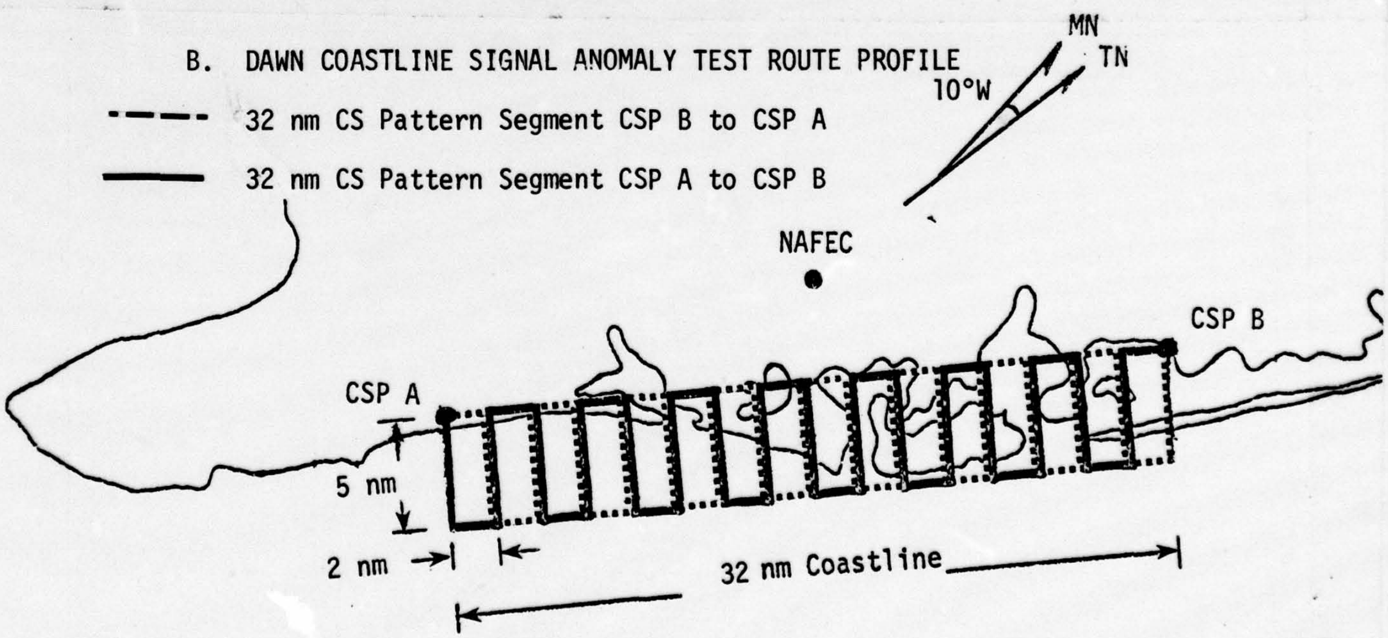


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Figure B.17 Coastline Signal Anomaly Route Profile

Table B.17 Coastline Signal Anomaly Route Definition

DUSK COASTLINE SIGNAL ANOMALY TEST DATA INPUT (Update Mode on C.M. Pad) 10° W. MAG. VAR.					
WAYPOINT	ALTITUDE MSL	LATITUDE	LONGITUDE	CUE LETTER	INPUT DATA
NAFEC, (R/W 04)		39° 26.95'	74° 35.15'		
CSP A	1000'	39° 22.63'	74° 30.12'	A B C D D E	CSP L,λ 5.0 nm 130° True LEFT 2.0 nm 16.0 nm
CSP B Climb to 2000' MSL at 16 nm to CSP C	1500'	39° 35.73'	74° 18.21'	A B C D D E	CSP L,λ 5.0 nm 130° True RIGHT 2.0 nm 32.0 nm
CSP C	2500'	39° 09.51'	74° 41.96'	A B C D D E	CSP L,λ 5.0 nm 130° True LEFT 2.0 nm 16.0 nm
Cape May		38° 56.63'	74° 53.08'		

DAWN COASTLINE SIGNAL ANOMALY TEST DATA INPUT (Update Mode on C.M. Pad) 10° W MAG. VAR.					
WAYPOINT	ALTITUDE MSL	LATITUDE	LONGITUDE	CUE LETTER	INPUT DATA
Cape May		38° 56.63'	74° 53.08'		
CSP A Descend to 2000' at 16 nm to CSP B	2500'	39° 09.51'	74° 41.96'	A B C D D E	CSP L,λ 5.0 nm 130° True LEFT 2.0 nm 32.0 nm
CSP B Descend to 1000' at 16 nm to CSP A (Climb higher if EAIR loses lock)	1500'	39° 35.73'	74° 18.21'	A B C D D E	CSP L,λ 5.0 nm 130° True RIGHT 2.0 nm 32.0 nm

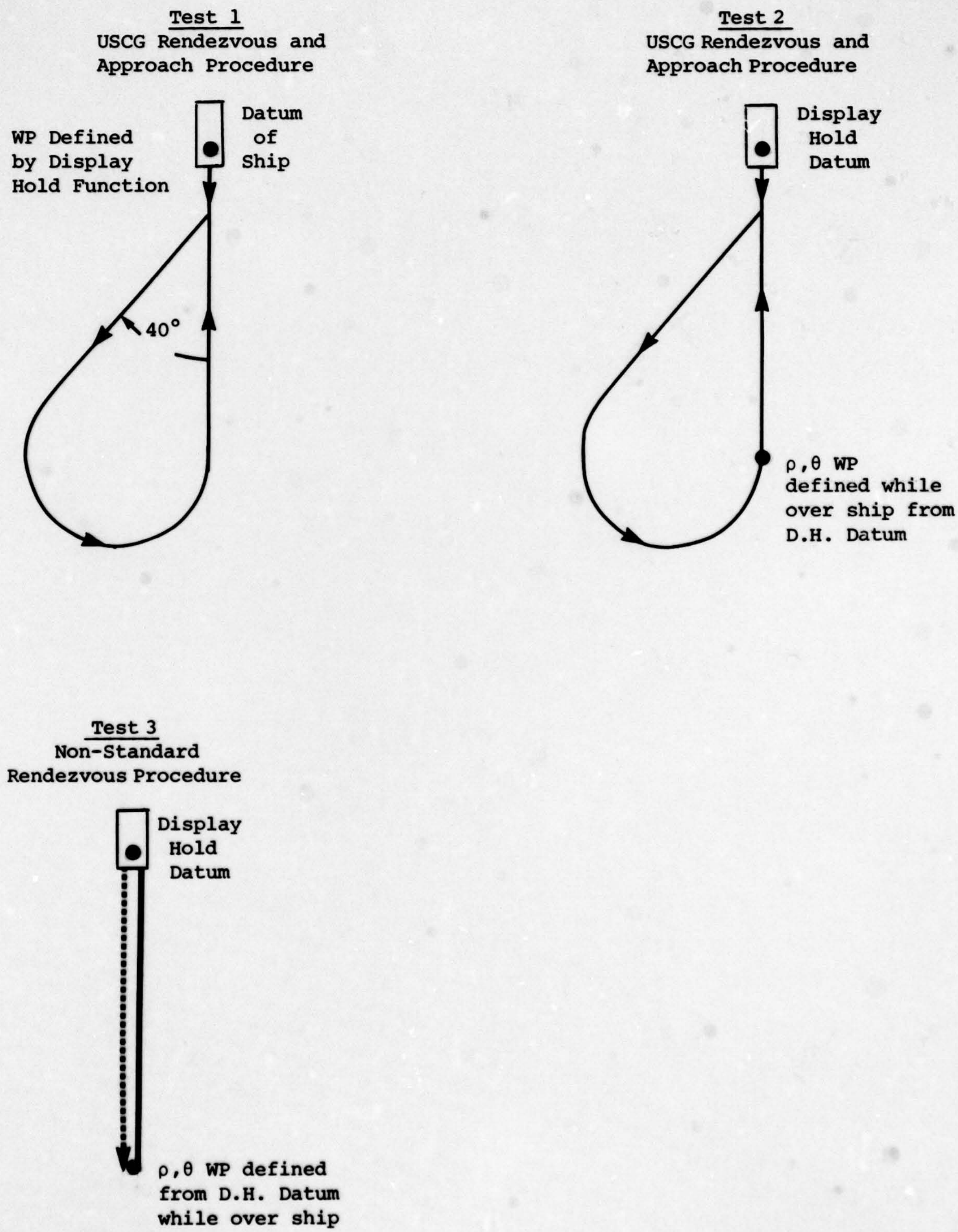

Figure B.18 Ship/Helo Rendezous Test Profiles

Table B.18 Ship/Helo Rendezvous Test Procedures

TEST 1 PROCEDURES

- 5 Approaches to **Stationary Ship**
- 5 Approaches to Moving Ship

1) Pilot proceeds to stern of ship.
2) Copilot creates Datum WP of ship position via Display Hold Function.
3) Pilot proceeds to make a procedural USCG HH52 rendezous and approach to ship.
4) Copilot selects leg change to Datum From Present Position when the Pilot completes standard rate turn and is stabilized on approach leg to ship.
5) Pilot begins beep-to-hover manuvers.
6) Pilot executes missed approach over stern of ship.
7) Proceed to complete a total of 5 approaches each to a stationary ship and moving ship.

TEST 2 PROCEDURES

- 5 Approaches to **Stationary Ship**
- 5 Approaches to Moving Ship

1) Pilot proceeds to stern of ship.
2) Copilot creates Datum WP of ship position via Display Hold Function.
3) Copilot creates FAF WP via σ,θ from Datum WP.

   σ = distance from ship may vary for several approaches to determine a comfortable distance for the beep-to-hover approach leg.

   θ = bearing downwind from ship.
4) Copilot selects manual leg change To FAF From Datum.
5) Pilot proceeds to FAF for approximately 0.25 nm as called out by copilot.
6) Pilot executes 40° standard rate turn.
7) Pilot proceeds on this heading to a point abeam FAF WP as determined by copilot.
8) Copilot calls out when abeam FAF WP (the DTW will decrease and then increase).
9) Pilot executes standard rate turn to the opposite direction from the initial turn to intercept the FAF WP.
10) Copilot will select manual leg change To Datum From FAF upon Arriving to the FAF WP.
11) Pilot will begin beep-to-hover per USCG procedures once the HH52 is stabilized heading to the Datum.
12) Pilot will execute missed approach over stern of ship.
13) Proceed to complete a total of 5 approaches to each stationary and moving ship.

TEST 3 PROCEDURES

- 5 Approaches to Stationary Ship
- 5 Approaches to Moving Ship

1) Pilot proceeds of ship.
2) Copilot creates Datum WP of ship position via Display Hold Function
3) Copilot creates FAF WP via σ,θ from Datum.
4) Copilot will select manual leg change to FAF from Datum.
5) Pilot will proceed on course to the FAF.
6) Copilot will select manual leg change to Datum from FAF upon arriving to the FAF WP.
7) Pilot will make a procedural turn to acquire the course heading to the Datum.
8) Pilot will begin beep-to-hover per USCG procedures once stabilized on course.
9) Pilot to complete a total of 5 approaches each to a stationary and moving ship.
10) Proceed to complete a total of 5 approaches each to a stationary and moving ship.

Test 3 utilized a non-standard procedural rendezvous pattern developed during earlier Loran-C testing. The only component common to all three tests is the approach leg. Test three defined waypoints the same as test two, Display Hold and ρ,θ. This test described the ability to fly a medium workload non-standard rendezvous in contrast to the high workload procedure.

Figure B.19 describes, in greater detail, the breakdown of the Ship/Helo rendezvous testing. There were a total of 17 approaches compiling two hours of test data.

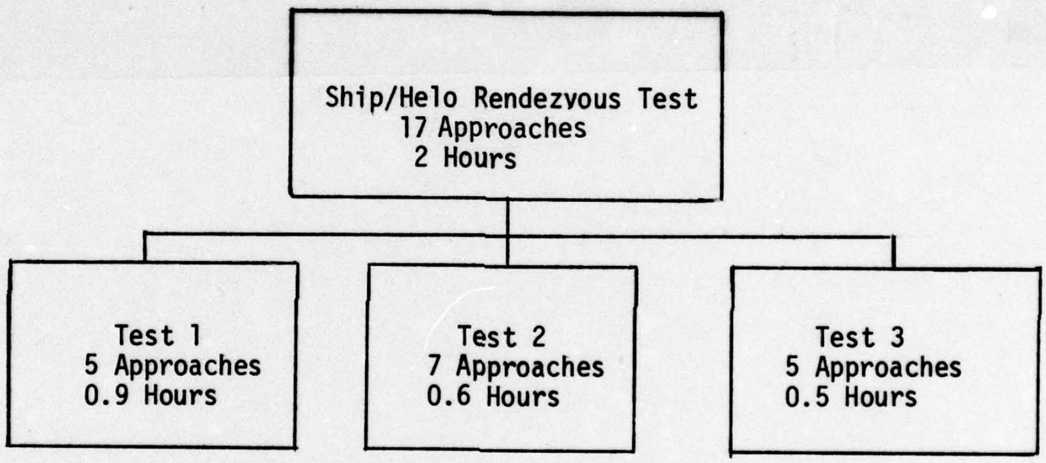

Figure B.19 Ship/Helo Rendezvous Test Diagram

D. OFFSHORE/OIL RIG TEST

An integral part of this Loran-C flight test evaluation was to demonstrate the Loran-C Navigator (AN/ARN-133) as an accurate navigation system which can be used for precision surveillance and enforcement missions. The test scenario chosen for these tests was in the Gulf of Mexico in the offshore area south of Mobile, Alabama. The test scenario also provided a limited amount of data pertinent to approach criteria for offshore oil rig operators. The test scenario utilized various clusters of offshore oil rigs in the test area. Figure B.20 presents the flight test profile applicable to this portion of the Loran-C operational evaluation. Accuracy and repeatability testing was performed as substantiation of the Loran-C applicability to the Coast Guard surveillance/enforcement mission and the offshore oil industry. For the purposes of these tests an HH52 helicopter based at Bates Field in Mobile, Alabama, was flown for a total of two flights. Each flight required approximately two hours. On both of these flights the Loran-C Navigator was operated in the lat/lon updated mode. The Loran-C update

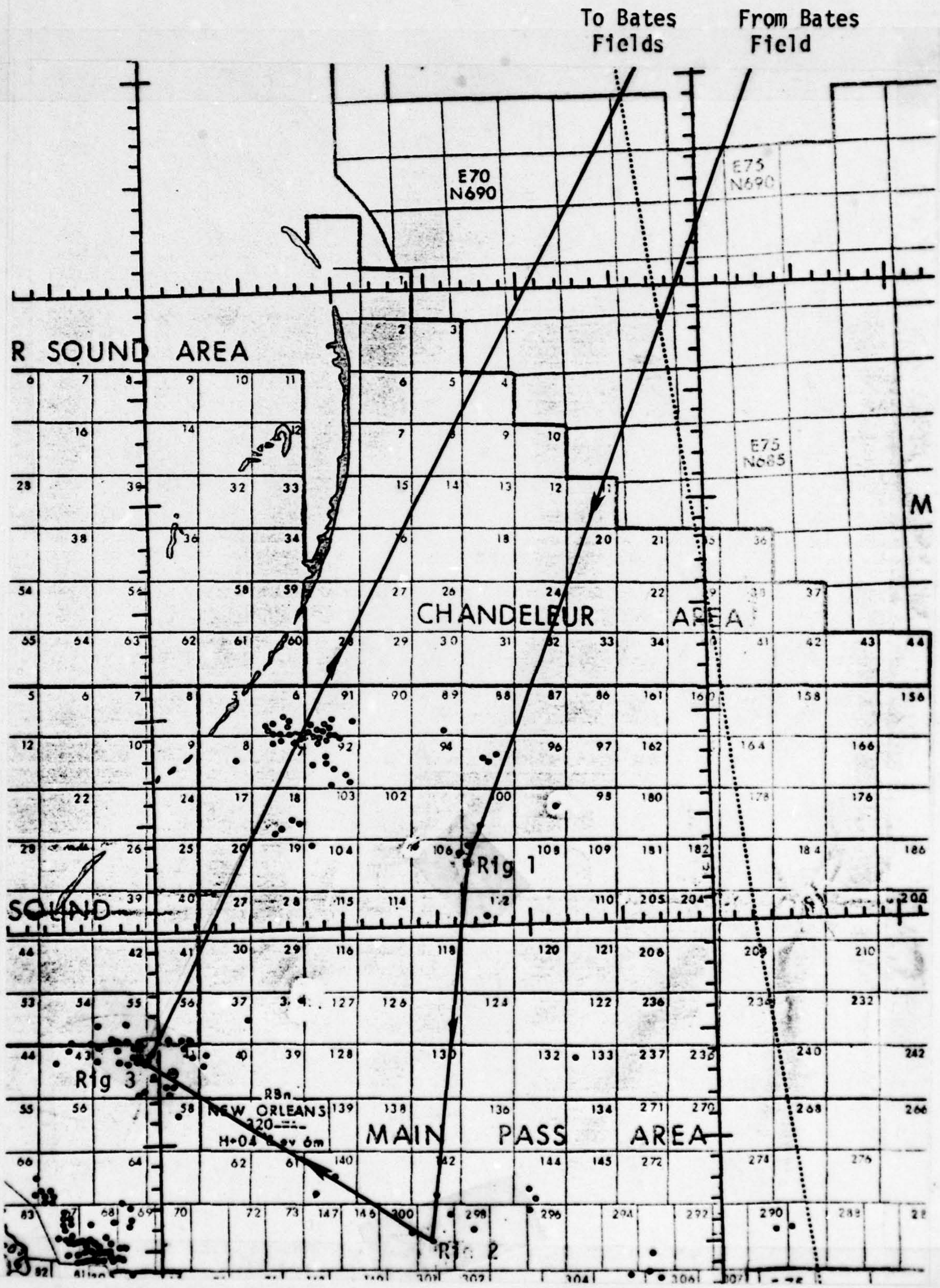

Figure B.20 Offshore/Oil Rig Test Scenario

was performed at the departing helipad at Bates Field. Figure B.20 shows the surveillance/oil rig missions beginning at Bates Field and proceeding direct to a selected oil rig which has been named number 1 for test purposes. This initial leg of the flight was approximately 69 nm south of Bates Field in the Gulf of Mexico. Upon reaching the oil rig, a stabilized hovering flight was performed next to the rig at an approximate position of 60 feet laterally and 20 vertically. The Loran-C indicated position (latitude/longitude) was recorded both manually (by test observer) and automatically by the airborne data recorder system for approximately two minutes. The data taken in this manner can be used to represent location and verification of an intruding vessel at sea or location and accurate positioning information suitable for landing on the oil rig platform. For the next leg of the flight, the Loran-C Navigator guided the aircraft to oil rig number 2 (17.4 nm from oil rig number 1), and then to oil rig number 3 (15.9 nm from oil rig number 2). Finally, the surveillance/oil rig flight transitioned for the return enroute segment to Bates Field, at which time the test flight was terminated. The data collection procedures were identical for all three oil rigs. The second surveillance/oil rig flight used lat/lon coordinates for each of the oil rigs (1, 2 and 3) measured on the previous flight. This particular test data demonstrated the repeatability accuracy mode of the Loran-C Navigator. The altitude at which the HH52 aircraft was flown during the respective enroute segments was consistent with normal Coast Guard operations.

Table B.19 defines the estimated waypoint locations, courses and distances necessary to define the desired surveillance/oil rig test pattern. The information in Table B.19 was developed using available charts.

Table B.19 Offshore/Oil Rig Test Pattern Definition

WAYPOINT	LATITUDE	LONGITUDE	TRUE COURSE (Deg)	MAGNETIC COURSE (Deg)	SEGMENT LENGTH (nm)
Bates	N030° 41.1'	W088° 14.0'	—	—	—
Oil Rig No. 1	N029° 32.5'	W088° 43.6'	200.1	196.1	73.5
Oil Rig No. 2	N029° 15.2'	W088° 45.5'	185.3	181.3	17.4
Oil Rig No. 3	N029° 23.9'	W089° 00.7'	303.3	299.3	15.9
Bates	N030° 41.1'	W088° 14.0'	27.0	23.0	87.3

/NOTE/
- ATD for a given flight is 194.1 nm.
- These lat/lon values are surveyed location from the USCG's ".... listing of offshore oil well structures and submerged wells in the Eighth Coast Guard District".

E. SAR OPERATIONAL TEST

A total of two flights (2.0 hours each) were allocated to validate the functional and operational utilization of the production Loran-C Navigator during search and rescue type missions. Of utmost importance on these tests was the flight test demonstration of the Loran-C Navigator capability to provide automatic guidance during the execution of Creeping Line and Sector Search type patterns. An additional feature of the production version of the Loran-C Navigator that was demonstrated was the capability to resume the search at the exact point where the search has been previously terminated. Departures from, and returns to, the exact point were performed once on each of the SAR patterns. The SAR test scenario was also used to check the functional operation of the Loran-C Navigator applicable to the parallel offsets and direct-to type maneuers. Of interest was the demonstration of continuous offset guidance until another waypoint angle bisector had been reached in the automatic waypoint sequencing mode. The direct-to test confirmed the capability of the Loran-C Navigator to provide guidance from present position to a waypoint defined in terms of a given distance (ρ) and bearing (θ) from a prestored waypoint.

General characteristics of the SAR operational tests included an approximate total track length of 125-145 nm in each flight. This translated into 2.0 flight hours for each SAR test based on average HH52 helicopter speeds. During the SAR tests the test aircraft cruised at an altitude not less than 2000 feet (MSL). This was of extreme importance since the test aircraft was being tracked by the NAFEC EAIR radar. An altitude lower than the 2000 feet specified would have degraded the capability of the EAIR radar to effectively maintain tracking.

The flight test profile executed during the operational search and rescue testing is illustrated in Figure B.21. This figure shows the test beginning at Cape May Air Station and proceeding enroute to the CSP (Commence Search Point) of a Creeping Line search pattern. Upon reaching the CSP, the HH52 helicopter immediately began a Creeping Line search of a fifty square mile area. A track spacing of two miles was used and a total of six legs, each 5.0 nm in length, were flown. Upon completion of the six legs of the Creeping Line search the aircraft immediately initiated a Sector Search. The Sector Search consisted of twelve sectors -- six legs and five cross legs -- with a central angle of thirty degrees.

After the last leg of the Sector Search had been flown, the aircraft proceeded direct to a rendezvous (R) waypoint defined as a range and bearing from a prestored intermediate (I) waypoint as shown in Figure B.21. The purpose of this maneuver was to simulate a rendezvous with another helicopter or a ship prior to proceeding with the remaining mission requirements. After reaching the rendezvous waypoint, the aircraft transitioned to an enroute segment direct to "H" waypoint, which had been prestored. Once on this segment, either a 3.0 nm left or 3.0 nm right parallel offset maneuver was flown. Upon reaching the bisector angle or at a distance to waypoint (DTW)

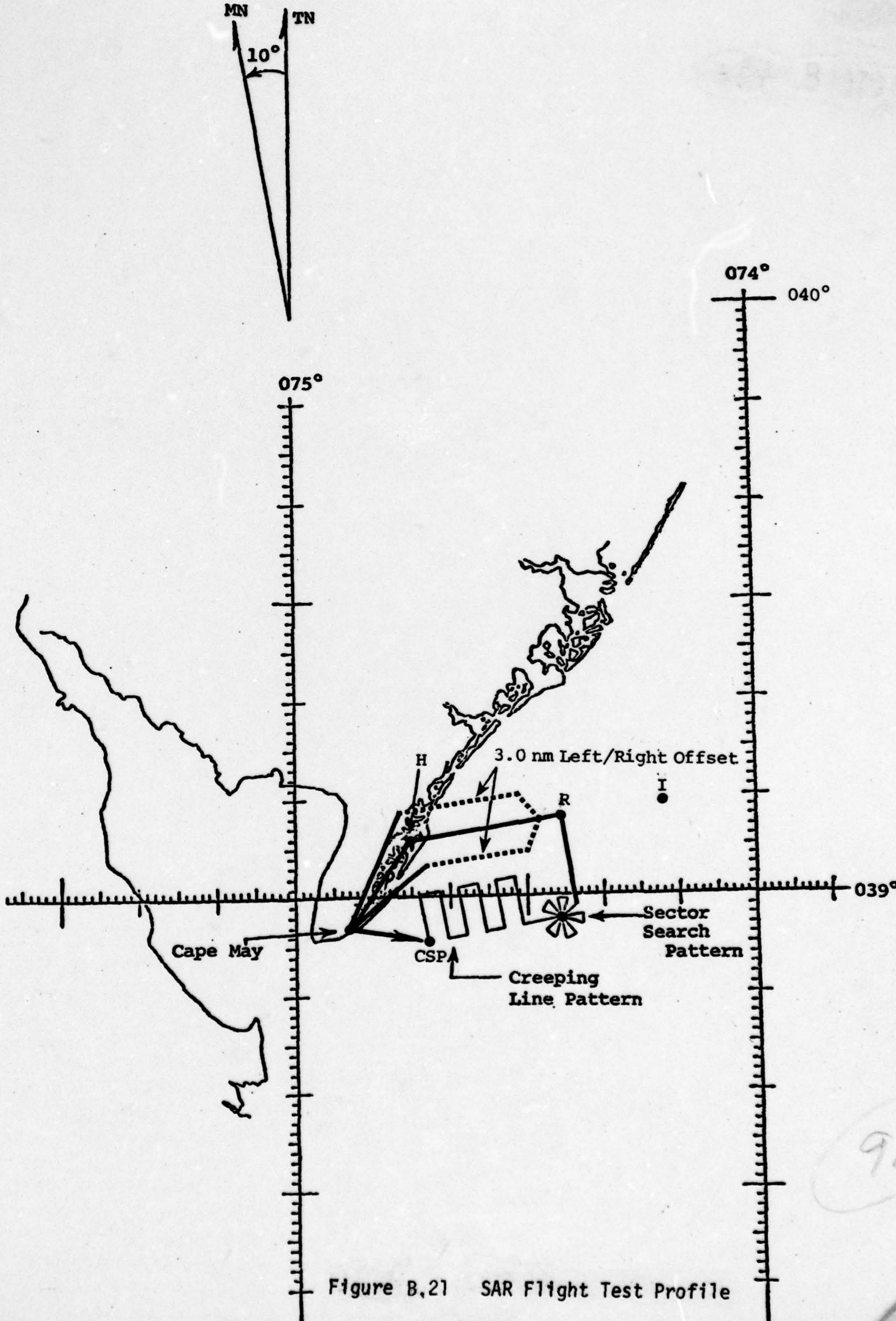

Figure B.21 SAR Flight Test Profile

of 0.0 nm to the offset waypoint, the parallel offset was terminated and the aircraft proceeded direct to the Cape May waypoint (air station) at which time the test was terminated.

Figure B.22 summarizes the SAR operational flight test matrix from a test sequence viewpoint. Both flights are similar as far as pilot/crew workload are concerned with the following exceptions:

1) Search data is entered and pre-stored prior to takeoff (first flight) vs entered inflight (second flight).

2) Discontinue and resume search variations.

3) 3.0 nm left vs 3.0 nm right parallel offset.

4) Direct-to guidance is from different locations depending on left or right offset maneuver.

Table B.20 illustrates in more detail the given test scenario for each of the two flights. For instance, both of these flights were flown in the lat/lon updated mode which was established by utilizing the actual position of the departure point from the helipad at the Cape May Air Station.

Table B.20 defines at which point of each search pattern and each flight, the search was temporarily interrupted and later resumed. To simulate interruption of search, the aircraft was deviated at least 3.5 nm off the search pattern and off course. Once the aircraft had deviated more than 3.5 nm miles from the search pattern, the pilot activated the resume search mode, which guided the aircraft to the resume search point in the search pattern. Table B.21 shows the lat/lon coordinates of the waypoints defining the SAR test profile. The distance and bearing (true) from waypoint 1 to the rendezvous waypoint (R) are, 10 nm and 260 degrees, respectively. These (ρ,θ) coordinates were input by the copilot during the departure from the sector SAR mission.

Table B.22 presents the specific set of data that must be entered into the Loran-C Navigator in order to execute the desired Creeping Line and Sector Search patterns. Figure B.23 and B.24 provide detailed waypoint location information for the Creeping Line and Sector Search patterns, respectively. These are presented for documentation purposes.

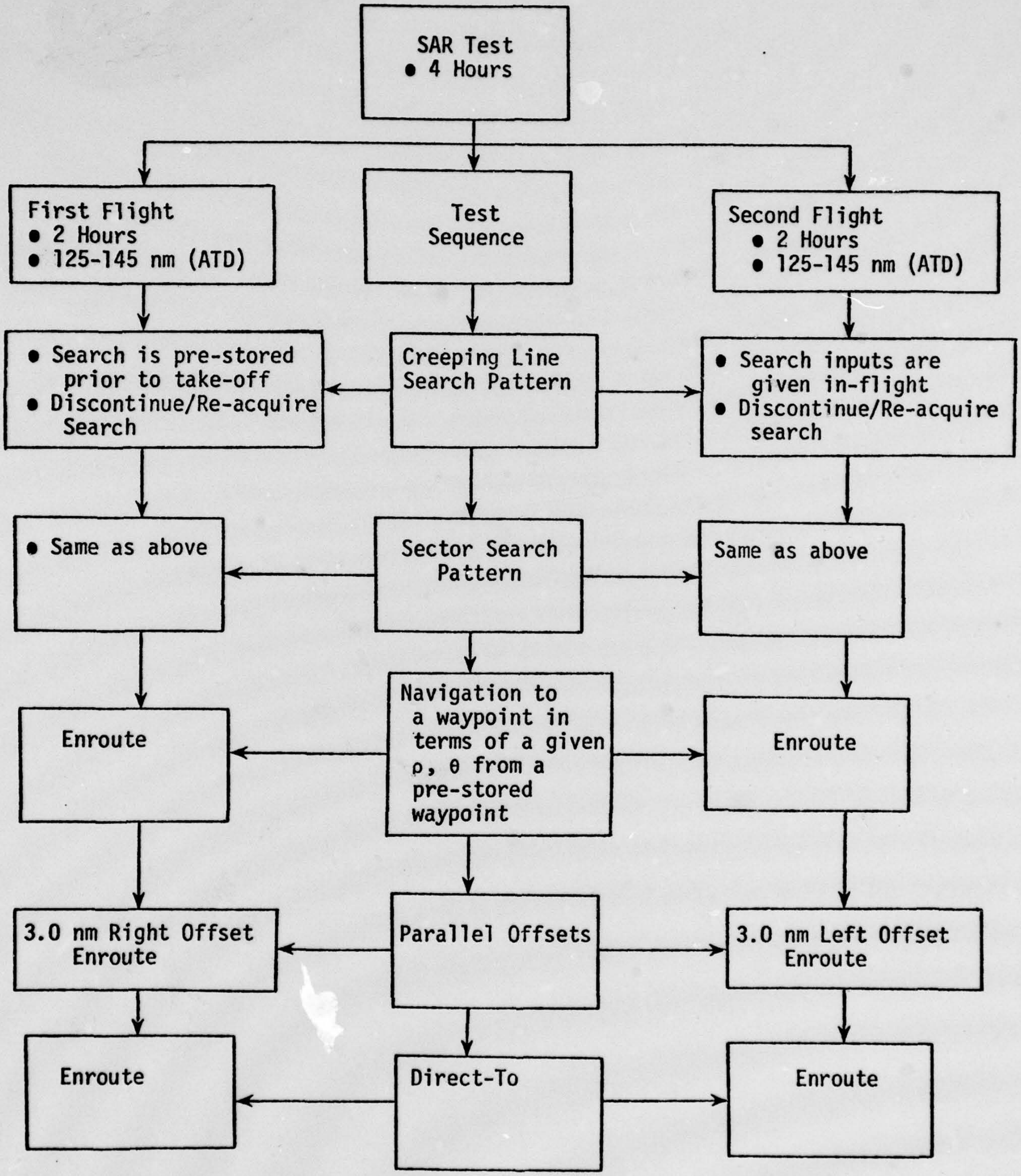

Figure B.22 SAR Flight Test Program

Table B.20 SAR OPERATIONAL TEST SCENARIO

ROUTE SEQUENCE	ATD (nm)	REMARKS	
		First SAR Mission	Second SAR Mission
Cape May to CSP of Creeping Line Pattern	8.0	Lat/Lon Update Prestore Search Patterns Prestore Search Patterns	Lat/Lon Update Input Search Pattern data in flight.
Perform Creeping Line Pattern	40.0	Depart Search and Resume Search in the middle of 4th leg, segment 1,2. Deviate from pattern approximately 3.5 nm.	Same as 1st SAR Mission
End of Creeping Line Pattern to CSP of Sector Search Pattern	4.0	Terminate Creeping Line Search on leg 6, segment 2,1. Proceed direct to CSP of Sector Search Pattern.	Aircraft may be put in a holding pattern until completion of in flight Sector Search data entry.
Perform Sector Search Pattern	35.0	Depart Search and Resume Search at middle of 4th leg, segment 1,2.	Same as 1st SAR Mission
End of Sector Search to Intermediate (I) Waypoint	—	Terminate Sector Search at end of leg 6, segment 1,2. Enroute to Waypoint I, create Waypoint R with ρ,θ from Waypoint I coordinates.	Same as 1st SAR Mission
End of Sector Search to Rendezvous (R) Waypoint	9.0	Proceed direct to Waypoint R once created.	Same as 1st SAR Mission
Rendezvous to Waypoint H	16.1 R Offset 13.8 L Offset	Execute 3.0 nm Right Parallel Offset. Cancel offset when DTW reads 0.0 nm to H.	Excute 3.0 nm Left Parallel Offset. Cancel offset when DTW reads 0.0 nm to H
H to Cape May	12.5 R Offset 10.5 L Offset	Proceed direct to Cape May	Same as 1st SAR Mission
Total Per SAR Mission	125-145		

Table B.21 SAR Test Waypoint Definition

WAYPOINT	LATITUDE Deg/Min. (North)	LONGITUDE Deg/Min. (West)
1 Cape May	038 56.63	074 53.08
2 CSP of Creeping Line Pattern	038 55.30	074 42.91
3 CSP of Sector Search Pattern	038 57.70	074 25.23
4 Intermediate[1]	039 09.57	074 12.57
5 Rendezvous[2]	039 07.85	074 25.28
6 H[3]	039 05.22	074 44.30

NOTE:

1. Intermediate (I) Waypoint will be used to fly to the Rendezvous (R) Waypoint by following the distance and bearing indicators from I to R waypoint.

   - Distance I TO R point is 10.01 nm.
   - True Bearing I TO R Waypoint is 260.17°.

2. "TO" Waypoint at the conclusion of the sector search pattern utilizing the given distance (10.01 nm) and true bearing (260.17°) from the Intermediate Waypoint.

3. Waypoint which defines the end of the enroute segment in which a 3.0 nm left/right parallel offset will be flown.

Table B.22 Creeping Line and Sector Search Loran-C Navigator Data Input

Lat/Lon Update Mode
(Cape May Helipad N38° 56.63'; W74° 53.08')
10° West Magnetic Variation

WAYPOINT NUMBER	WAYPOINT NAME	CUE LETTER	SEARCH PATTERN INPUT DATA		LATITUDE (Deg. & Min.)	LONGITUDE (Deg. & Min.)
1	Cape May (CM)				N38° 56.63'	W74° 53.08'
2	Creeping Line CSP	A B C D D E	Lat/Lon Leg Length BRG. of 1st Leg Direction of 1st Turn Track Spacing Pattern Length	 5.0 nm 350° (True) Right 2.0 nm 10.0 nm	N38° 55.30'	W74° 42.91'
3	Sector Search CSP *	A B C D D	Lat/Lon Leg Length BRG. of 1st Leg Direction of 1st Turn Track Spacing	 2.0 nm 80° (True) Right 0.52 nm†	N38° 57.70'	W74° 25.23'
4	Intermediate (I)**				N39° 09.57'	W74° 12.57'
5	Rendezvous (R)		Input ρ, θ = 10.01 nm, 260.17° (True) from WP (I) Lat, Lon			
6	H ††				N39° 05.22'	W74° 44.30'
7	Cape May (CM)				N38° 56.63'	W74° 53.08'

NOTE **After the last leg of the Sector Search has been flown, proceed direct to waypoint I. While enroute to waypoint I, proceed direct to waypoint R, created by range and bearing (True) (10.01 nm, 260.17°) from waypoint I coordinates.

††Waypoint H defines the end of the enroute segment in which a 3.0 nm left or right parallel offset will be flown.

*Sector Search Pattern has 5 cross legs at 30° centered angle. Each leg is 4.0 nm through the CSP (datum).

†Derived using ($L \sin \frac{180}{NL} = T$) and where L is leg length; NL is number of legs and T is track spacing

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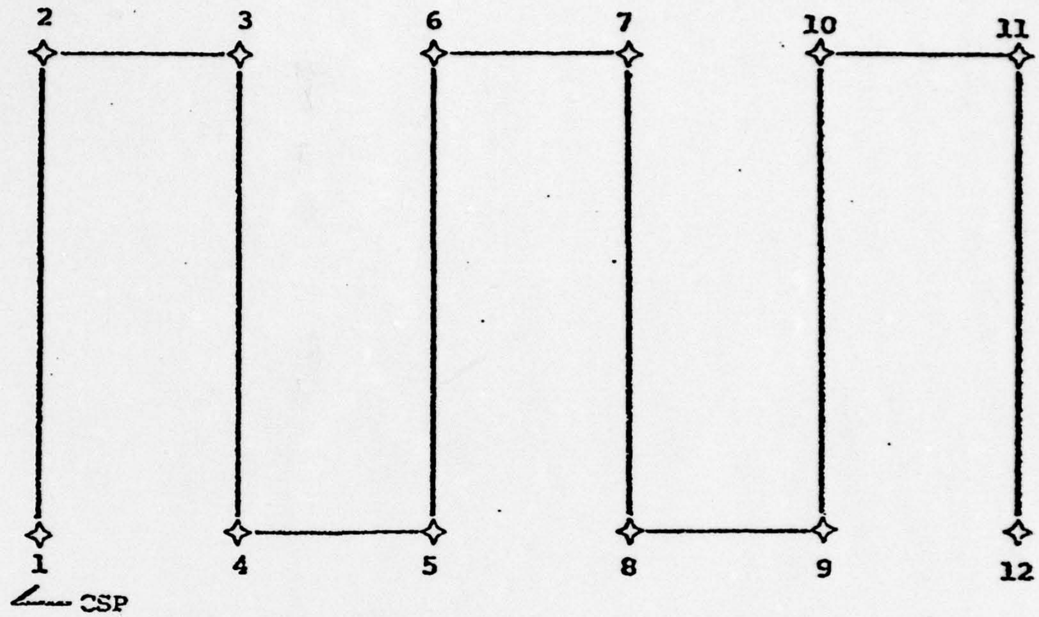
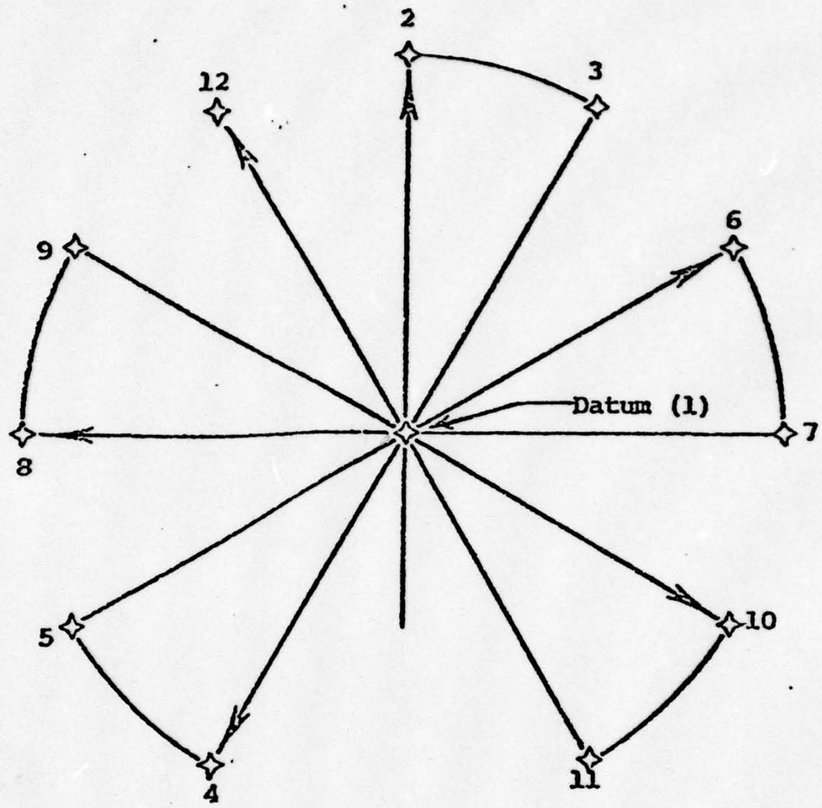


WAYPOINT	LATITUDE (N)	LONGITUDE (W)	TRUE COURSE (deg)	MAGNETIC COURSE (deg)	ALONGTRACK DISTANCE (nm)
1 (CSP)	038° 55.30'	074° 42.91'	—	—	—
2	039° 00.21'	074° 44.03'	350	0,360	5.0
3	039° 00.56'	074° 41.50'	080	090	2.0
4	038° 55.65'	074° 40.38'	170	180	5.0
5	038° 56.00'	074° 37.86'	080	090	2.0
6	039° 00.91'	074° 38.98'	350	0,360	5.0
7	039° 01.25'	074° 36.45'	080	090	2.0
8	038° 56.33'	074° 35.33'	170	180	5.0
9	038° 56.68'	074° 32.81'	080	090	2.0
10	039° 01.60'	074° 33.93'	350	0,360	5.0
11	039° 01.95'	074° 31.40'	080	090	2.0
12	038° 57.01'	074° 30.28'	170	180	5.0

Figure B.23 SAR Creeping Line Pattern Definition



WAYPOINT	LATITUDE (N)	LONGITUDE (W)	TRUE COURSE (deg)	MAGNETIC COURSE (deg)	ALONGTRACK DISTANCE (nm)
1	038° 57.70'	074° 25.23'	—	—	—
2	038° 58.05'	074° 22.71'	080	090	2.0
3	038° 57.01'	074° 22.83'	185	195	1.0
4	038° 58.38'	074° 27.63'	290	300	4.0
5	038° 59.23'	074° 26.88'	034	044	1.0
6	038° 56.16'	074° 23.58'	140	150	4.0
7	038° 55.73'	074° 24.78'	245	255	1.0
8	038° 59.66'	074° 25.68'	350	0,360	4.0
9	038° 59.58'	074° 24.35'	095	105	1.0
10	038° 55.81'	074° 26.10'	200	210	4.0
11	038° 56.41'	074° 27.18'	305	315	1.0
12	038° 58.98'	074° 23.26'	050	060	4.0

Figure B.24 SAR Sector Search Pattern Definition

APPENDIX C

DATA ACQUISITION

AND

PROCESSING REQUIREMENTS

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APPENDIX C

C.1 DATA ACQUISITION AND PROCESSING REQUIREMENTS

The data acquisition and data processing capabilities used to support the analysis of the AN/ARN-133 Loran-C Navigator Flight Tests are discussed in this section. Section C.1.1 describes in detail the data acquisition requirements. Included in Section C.1.1 is a detailed discussion of the types of data acquired. These types of data were: Airborne Instrumentation (Section C.1.1.1); Ground Reference (Section C.1.1.2), which included both EAIR and ARTS III radar tracking facilities; and the Manually Recorded Flight Logs (Section C.1.1.3), which were recorded by the test observer. In addition, Section C.1.1) discusses the Time Correlation Procedures (Section C.1.1.4) used during the flight tests, as well as the Data Acquisition and Processing Logistics (Section C.1.1.5). The data processing requirements are discussed in Section C.1.2. Included in this section is a discussion of the data processing required by test topic (Section C.1.2.1), as well as the specific data processing required for AC 90-45A compliance (Section C.1.2.2).

C.1.1 Data Acquisition Requirements

This section discusses the methods of data acquisition utilized in the USCG Loran-C flight test program. There were three categories or classes of data that were recorded during the Loran-C flight test program for the purposes of providing a substantiating data base for the various levels of analysis required to support the Loran-C operational evaluation. The three distinct types of recorded data were:

1. Airborne Instrumentation Data
2. Ground Reference
3. Manually Recorded Flight Logs

The following paragraphs discuss each of these different methods of data acquisition. Included also is a discussion on time correlation (airborne and ground reference data) procedures followed during the entire Loran-C flight test program.

C.1.1.1 Airborne Instrumentation

The two test aircraft were instrumented with a digital recorder system capable of recording the required parameters in a continuous permanent format (tape or cassette) suitable for subsequent computer processing. The following measurements were electronically recorded from the Loran-C receiver on the airborne data recording system.

1. Loran-C indicated aircraft position (latitude and longitude).
2. Crosstrack Deviation (CTD).
3. Distance-to-Waypoint (DTW).
4. Elapsed Time.

The Crosstrack Deviation Indicator (CDI needle deflection) located on the pilot's instrument panel was calibrated prior to the overall flight test program to assure the validity of the recorded CTD measurement from the Loran-C receiver. This was of extreme importance, since, as an operational procedure, the pilot will more likely be flying according to the CDI needle rather than the digital CTD displayed on the Loran-C control display unit.

C.1.1.2 **Ground Reference Data**

Tracking data was required to verify the absolute airborne total system accuracy and the acceptability of prespecified aircraft routes and maneuvers. Tracking data was derived from the precision tracking facility (Extended Area Instrumentation Radar, EAIR) at the National Aviation Facilities Experimental Center (NAFEC) and from the Automated Radar Terminal System (ARTS III). Table C.1 presents all of the flight test tasks on this flight test program and specifies the type of radar coverage required (ARTS or EAIR radar) by each task. The following paragraphs discuss each of these radar tracking facilities, including the data measurements that were recorded.

ARTS Tracking Radars

The ground reference data collected during the Northeast Corridor tests was obtained using the FAA/ARTS III type radars, which normally provide coverage within 50 nm of the antenna site location, and which are primarily used during ATC terminal area operations. Although the tracking accuracy of the ARTS III radar degrades in an angular fashion as distance from the facility increases, no precision tracking radar or other alternative was available for these tests. In the Northeast Corridor test route (Washington, D.C. to Boston) there are seven ARTS radars which, because of their respective locations, collectively provided the required tracking coverage of the test aircraft. This tracking data was not expected to provide precise Loran-C accuracy statistics but simply to be used to determine the location of the test aircraft within the ±2 nm route width of the Northeast Corridor or to determine when the ±2 nm boundary was exceeded.

The expected coverage capability and location of the seven Northeast Corridor radar facilities was indicated in Section B.1, Figure B.2 superimposed on the Northeast Corridor test route. These ARTS radars provided the following measurements for the test aircraft:

1. Azimuth
2. Range
3. Altitude (through the aircraft's encoding altimeter)
4. Data Validity
5. Aircraft Transponder Ident, when activated by the pilot, for time correlation purposes
6. Time of Day (Greenwich)

Table C.1 Ground Reference Coverage Requirements per Flight Test Task

FLIGHT TEST TASK	TEST HELICOPTER	TYPE OF RADAR COVERAGE REQUIRED		REMARKS
		ARTS	EAIR	
Northeast Corridor (Boston-DCA-Boston) and spur routes	HH-3 & HH-52	X		Tracking required throughout flights. A total of seven (7) ARTS type radars at different locations along the test route.
Deep Probe Overwater (NAFEC)	HH-3		X	Tracking required for the first and last 100 nm of the test flight.
Radar Accuracy Correlation (NAFEC-Philadelphia area)	HH-52	X	X	Established accuracy correlation between ARTS and EAIR radars.
NAS (NAFEC)	HH-52 & HH-3		X	None
Coastline (NAFEC)	HH-52		X	None
SAR (NAFEC)	HH-52		X	None
Surveillance/ Oil Rig	HH-52	—	—	Airborne Data Only

Table C.2 lists the applicable ARTS III facilities and their locations. These facilities provided coverage of the Northeast Corridor test route in its entirety.

Table C.2 ARTS III Facilities Which Provided Coverage of Northeast Corridor Routes

AIRPORT NAME	ASSOC. CITY	LAT	LON
Washington National	Washington, D.C.	N38°-50'-42.0"	W77°-02'-01.0"
Baltimore-Wash. Int.	Baltimore	N39°-10'-44.1"	W76°-41'-01.8"
Philadelphia Int.	Philadelphia	N39°-51'-34.1"	W75°-16'-02.3"
JFK Int.	New York	N40°-38'-10.2"	W73°-46'-02.4"
Bradley Int.	Windsor Locks(Ct)	N41°-56'-19.0"	W72°-41'-01.0"
Logan Int.	Boston	N42°-20'-55.7"	W71°-00'-22.8"
Naval Air Station	Quonset Point	N41°-36'-08.0"	W71°-24'-42.0"

EAIR Tracking Radar

The ground reference data for those tests which originated from NAFEC and/or the USCG Cape May Air Station was provided by the Extended Area Instrumentation Radar (EAIR). EAIR is a precision, C-band tracking radar which provides the slant range, azimuth angle and elevation angle of an aircraft within a range of 100 nautical miles when operating in the skin tracking mode, with a maximum distance of 190 nautical miles when operated in the beacon tracking mode. (All of the Loran-C test flights were tracked in the beacon tracking mode). The slant range obtained by the EAIR facility is accurate to within 20 yards and the azimuth angle and elevation angle are accurate to within 0.011 degrees. For example, at 50 miles the accuracy would be 20 yards in range and 20 yards in azimuth and elevation. The radar antenna can track a target 360° in azimuth and from 0° to +89° in elevation. The antenna can be directed as low as minus one and one-half degrees in elevation. The NAFEC EAIR tracking radar provided the following measurements of the test aircraft:

1. Azimuth
2. Elevation
3. Range
4. Altitude
5. Real Time (Local)

In addition, the EAIR radar provided tracking plots which show the desired path vs actual path flown by the test aircraft. Since the test aircraft was tracked in radar C-band beacon mode, it required that the test aircraft be equipped with a C-band beacon transponder. This was made available by the NAFEC EAIR tracking facility, but its installation on the test aircraft was performed by the USCG. The radar C-band beacon antenna was calibrated at least every other day (or as frequently as required) to insure the accuracy of the EAIR radar. The calibration procedure was simply to land at NAFEC and taxi to a known position. Radar lock-on was achieved and position accuracy established.

C.1.1.3 Manually Recorded Flight Logs

During all flight tests, a trained cockpit observer monitored and kept an accurate log of routine and special events that occurred during the flight. This log has proven to be an invaluable aid in reconstructing occurrences leading up to potential "bad" data points. Logs have also been a major source of data from which flight test results could be operationally and qualitatively evaluated. To this end, the test engineer manually recorded the following data for additional information relative to the evaluation of the specifics test objectives:

1. Procedural errors, defining most probable cause
2. Input errors
3. Loran-C display mode
4. Waypoint in use
5. Waypoint sequencing mode (auto/manual)
6. Major cross track deviations (CDI)
7. Overshoot/undershoots
8. Execution of offsets and other impromptu maneuvers
9. Loran-C operations (lat/lon, time differences, initialization, time to acquire/track selected master/station pairs, loss of signal, re-acquiring in-flight, etc.)
10. Track heading intercepts
11. Pilot workload (impromptu, communication, traffic, weather, etc.)
12. Time noted for aircraft maneuvers (heading change, altitude change)

A brief summary of flight test events was written at the conclusion of each test by the test engineer/observer. The subject pilot's comments were incorporated in this report in order to document a particular event or reason for decision-making during the flight testing. In addition to the above duties, the cockpit observer operated and monitored the airborne data recorder system.

C.1.1.4 Time Correlation

In order to fulfill the data requirements of the overall flight test program, careful attention was given to the establishment of time correlation procedures between the airborne data recorded and the ground tracking facility data. This section discusses the time correlation procedures used when operating with the ARTS and/or EAIR ground tracking facilities. Since ARTS usage involved the most rigorous time correlation requirements, these procedures are addressed first.

ARTS Ground Tracking Facilities

During the Northeast Corridor tests, ARTS tracking data was used to verify the actual aircraft position relative to the ±2 nm route width and the acceptability of performing required ATC operational maneuvers. The establishment of time correlation procedures between the airborne data recorded and the ground tracking facility was complicated by the fact that a minimum of seven ARTS radars were utilized to provide the intended coverage of the test aircraft during the Northeast Corridor tests (see Figure B.2). This was a result of the expected tracking range of the ARTS facility, which is about 50 nm. It was necessary to maintain time sychronization between facilities. One preventative measure used to assure the accuracy of the time correlation was to use the aircraft's transponder "ident" feature at various points along the flight path, since once it was activated by the pilot, that fact was recorded on the ARTS ground facility data recording system. The airborne time was noted at the time of the "ident" action, which then defines the time correlation between airborne and ground data. This particular technique was satisfactorily employed during previous flight tests (Reference 2) utilizing only a single ARTS facility. The accuracy of the time correlation was estimated to be within a maximum of ±2 seconds, due to the normal ARTS antenna rotation period of four seconds for a complete 360° scan. A second method of time correlation used was to request the ATC controller for a 10 second countdown "time hack" utilizing the time displayed on the ARTS radar display. At the precise time the ATC controller read the "mark time", the pilot of the test aircraft activated the "ident" feature, while the test engineer noted this value and also the airborne time. When followed accurately, this second method improved time correlation accuracy to within one second. However, in order to minimize the possible human errors that may have been introduced inadvertently by the test engineer and/or ATC controller in noting their respective times, the "time hack" correlation was performed immediately before or after the "ident" type time correlation. This assured the validity of the time correlation, since it could be checked redundantly by two independent methods. Time correlation was established whenever the test aircraft was within the coverage area of a particular ARTS facility along the Northeast Corridor. Table C.3 presents the Northeast Corridor test route flown by the test aircraft on a segment by segment basis vs which ARTS facility tracked the test aircraft at that time. At least two "idents" and one "time hack" time correlations were performed for each ARTS radar. The timing of when to do the time correlations was left to the judgment of the pilot in conjunction with the availability of the ATC controller to comply with the pilot's request.

Finally, an item that required close coordination concerned the transponder code the test aircraft utilized for ATC identification purposes. This was extremely important since, in the ARTS data recovery phase, the data was retrieved according to the specific transponder code assigned to the test aircraft. Therefore, no VFR transponder code numbers could be used during that portion of the testing which utilizes ARTS data, since it would be impossible to distinguish which code belongs to what aircraft. Rather, a specific discrete transponder code was assigned to the test aircraft, and remained fixed throughout the entire flight. To document which identification

code was used, the test engineer included in his flight logs the transponder code used and the handoff times from each ARTS facility to the next.

Table C.3 Route Segments of the Northeast Corridor Test Route Where Time Correlation Were Performed For Each ARTS Facility Coverage

ARTS FACILITY	SOUTHBOUND SEGMENTS	TIME CORRELATION Time Hack	Ident
Logan Int.	To ROGEE	X	X
	MOURO to CLINT		X
Naval Air Station	To ROGEE	X	X
	MOURO to CLINT		X
Bradley Int.	MOURO to CLINT	X	X
	CLINT to MUSIK		
JFK Int.	MUSIK to FLOPP	X	X
	TOLAN to SLONE		X
PHL Int.	SLONE to HAYER	X	X
	WAGGS to WINGO		X
BAL Int.	WINGO to EGNER	X	X
	TAYLO to RINTY		X
DCA	TAYLO to RINTY	X	X
	After PISA Complete		X
	NORTHBOUND		
DCA	To BERNY	X	X
	MOISH to RUSEY		X
BAL Int.	MOISH to RUSEY	X	X
	ABZUG to ZOIDS		X
PHL Int.	ABZUG to ZOIDS	X	X
	TULLY to JONNS		X
JFK Int.	JONNS to BANKA	X	X
	MAUDE to FLOPP		X
Bradley Int.	IGORR to DROUN	X	X
	DROUN to DANEY		X
Naval Air Staion	DROUN to DANEY	X	X
	MEEOW to SLOTT		X
BOS Int.	DANEY to MEEOW	X	X
	After PISA Complete		

EAIR Ground Tracking Facility

The procedure required to establish time correlation between NAFEC EAIR tracking radar and the airborne data recorder system utilized a digital clock synchronized to EAIR radar real time telephonically just prior to flight. This was necessary since the airborne data recorder system showed elapsed time when the Loran-C Navigator was turned "ON", and did not have the capability of synchronizing to EAIR radar real time.

The manual report function of the Loran-C Navigator provides a convenient method of entering EAIR synchronized airborne time into the Navigator and "reported" into the data recording system with a corresponding elapsed time. This procedure was repeated several times during the test flight to assure accuracy of the time correlation to approximately one second.

C.1.1.5 Data Acquisition and Processing Logistics

In order to achieve the objectives of the flight test and to assure data quality, the following data recording, recovery and processing steps were performed:

1) Digital recording of airborne Loran parameters (lat/lon, CTD/DTW, time).

2) Quick-look capability for airborne data quality assurance.

3) Digital recording of ground radar tracking data (ARTS and EAIR).

4) Production of CDC-compatible tracking data tapes, as follows:
   - Conversion of raw EAIR tapes to lat/lon coordinates (seven track BCD)
   - Extraction of test aircraft raw digitized radar data from ARTS data log tapes (seven track packed binary)

5) EAIR radar plots of aircraft true flight path.

6) Manually recorded flight test observer logs.

7) Data editing and time-correlated merge procedures.

8) Error analysis and statistics production.

In addition to the above steps which were required for the determination of system accuracy in NAS and USCG operational environments, special (or limited) data recovery steps were required for the ARTS/EAIR radar correlation demonstration, the offshore/oil rig tests and the ship/helo rendezvous tests. These steps are discussed in more detail in the following paragraphs.

Loran Data Recording and Recovery

The telemetry capability built into the navigator (as modified for purposes of this test) was utilized to record Loran parameters. The system

outputs data in Bell 202C-compatible format, which was recorded directly on audio cassette tapes. The system outputted the lat/lon/time data and the CTD/DTW/time data alternately every three seconds. The Coast Guard provided equipment necessary to play back the tape on the ground for quick-look purposes for the flight test observer. This consisted of a Texas Instrument Silent 700 (Model 743-KSR) Terminal and Collins Model 1200D MODEM (Bell 202C). Periodic checks of airborne data integrity were performed by listing parts of tapes on the portable printer.

Actual loading of the data onto the CDC timesharing system was accomplished from the contractor's office using the Collins MODEM.

ARTS Data Coordination and Recovery

The ARTS sites have the capability of recording tracking data (raw digitized secondary radar output as well as other data) for all aircraft under surveillance at any given time. It was possible to recover this data and isolate the tracking data for an individual aircraft based on a unique transponder code. Through an effort coordinated between the FAA and the Coast Guard, data was obtained from several ARTS sites, including the following seven: Washington, Baltimore, Philadelphia, New York, Windsor Locks, Quonset Point and Boston. All were ARTS III sites except New York, which was an ARTS IA. The ARTS III sites record data in a common format. At Washington data was recorded continuously, whereas at the other sites additional coordination was required to assure that data recording was taking place while the test aircraft was in the coverage area. The ARTS III facilities were not capable of reducing the raw tapes to produce tapes containing test-aircraft data only. The New York ARTS IA data was in a different format. Recovery of this data required further coordination between the FAA and the USCG.

Successful utilization of ARTS tracking data required careful coordination on the days on which data flights were made. Each facility was apprised of the approximate time the aircraft would be within coverage range. It was necessary in some cases to coordinate by radio with those facilities which do not normally record data continuously. Post-flight coordination was also required to insure that tapes were sent to CDC.

EAIR Data Coordination and Recovery

After overall arrangements for EAIR tracking had been made between the Coast Guard and NAFEC, appointments for range time were required. Prior to departure in each case, the EAIR operators were informed as to the desired plot scale and tracking data recording requirements. Tapes were processed by NAFEC to convert the EAIR coordinates to Lat/Lon as a matter of course. Tapes were then sent to CDC in Rockville on a loan basis.

Data Editing and Time Correlation

Time synchronization between the airborne clock and the ground clock at the NAFEC EAIR facility was achieved telephonically prior to flight.

Time correlation with the ARTS facilities was a much more involved task, as explained in Section C.1.1.4. Time correlation was achieved for each separate ARTS facility based on the data in the observer logs and the IDENT responses recorded on the ARTS data tapes.

All data was reviewed and edited, both manually and automatically. The observer log was used to edit (flag) Loran data which should not be included in the statistical analysis. The data was then passed through a program which noted discontinuities in the data. These were then manually reviewed and edited (flagged) where the discontinuities represent data recording or recovery errors. The ARTS data was passed through a program which rejected false returns and noted discontinuities. These were reviewed and edited. All files representing pieces of an individual flight were combined to form a continuous file of data for each flight. The EAIR radar data was passed through an existing program which tested for discontinuities, which were then corrected or edited.

Based upon the time correlation data, each airborne Loran data file was time-merged with the appropriate radar (ARTS or EAIR) file in preparation for the error analysis step. For each Loran data point recorded ground-derived aircraft position was computed by linear interpolation of the two nearest points. A complete, merged data file was prepared for each flight. A program was developed for each of these steps and used successfully on earlier flight test support efforts.

Error Analysis and Statistical Evaluation

Using an existing Loran error analysis program, each of the merged data points was compared to the intended route of flight, and along track/cross track and Northing/Easting errors were computed. Errors were aggregated along each route segment and statistics for each segment (mean, standard deviation, skewness and kurtosis) were computed. The error quantities computed were Total System Crosstrack Error, Flight Technical Error, Airborne System Error and Alongtrack Error.

Other Data Processing Requirements

The ARTS/EAIR correlation demonstration was performed by time-merging the ARTS and EAIR data using a modified version of the Loran merge program. A special error analysis was performed where ARTS range and bearing errors, as well as the north and east components, were calculated and statistics computed over each flight leg.

The Loran data collected by the ground receiving system during the telemetry tests was plotted in real time and the resulting plot was compared to the EAIR radar plot for verification purposes.

The Loran position data collected during the offshore/oil rig test was reduced manually into sets of root mean square distance error (d_{rms}) absolute Loran-C surveillance/oil rig location position accuracy determination as well as establishing Loran-C navigator repeatability, that is, the ability of the Loran-C navigator to return precisely to a location defined by a previous flight.

C.1.2 Data Processing Requirements

This section delineates the specific data output elements provided in response to the test objectives and test matrix elements. In particular, Section C.1.2.1 discusses the data processing requirements necessary to support each of the test matrix elements developed in Section B.1 and illustrated in Figure B.1. This detailed discussion is followed by Section C.1.2.2 which explicitly addresses the accuracy criteria set forth for compliance in FAA Advisory Circular 90-45A, how these criteria were satisfied and what specific error elements were developed from the Loran-C navigator testing.

C.1.2.1 Data Processing By Test Topic

There were basically two levels of data processing required to support the operational evaluation of the Loran-C navigator. The first and most rigorous processing requirements evolve from those tests which necessitate both quantitative and qualitative results. This type of test required statistical processing of all measured ground and airborne data. In the case of the Loran-C evaluation, statistics were defined by four basic performance measures:

TSCT - Total System Cross Track Error

This error is defined as the actual aircraft deviation perpendicular to the desired course in the horizontal reference plane. TSCT was measured with precision tracking radar for the NAFEC tests and using ARTS III and IA radar for the operational testing.

FTE - Flight Technical Error

This error is defined as the indicated amount of deviation from the desired course in the horizontal reference plane. The quantification of FTE was obtained by electronically measuring and recording deflections of the Cross Track Deviation Indicator (CDI)

ASE - Airborne System Error

This error is defined as the composite error contributed by all airborne navigation equipment including sensors, receivers, computers, displays and any calibration, scaling or interconnecting errors peculiar to the system being evaluated.

ATE - Along Track Error

This error is defined as the actual aircraft deviation from the desired position along the flight path. ATE results from the total error contributions of the airborne and ground equipment only. No FTE is used in determining the along track error. ATE was measured using precision tracking radar for the NAFEC tests and using ARTS III and IA radar for the operational testing.

Both mean or bias errors (magnitude and direction) and two-sigma variability errors were calculated for TSCT, FTE, ASE and ATE where required. In addition, it was necessary to calculate skewness and kurtosis for these error quantities. These quantities are specific tests of an error distribution's similarity in shape and form to a normal distribution. The two values which indicate this similarity are the coefficient of skew and the coefficient of kurtosis. The coefficient of skew evaluates the asymmetry, or skewness, of a given distribution. If the frequency curve of a distribution has a longer "tail" to the right of the central maximum than to the left, the distribution is displaying a positive skew or skewness to the right. If the reverse is true, the distribution is skewed to the left or has negative skewness. The coefficient of skew is zero if the frequency distribution curve is symmetrical with that of a normal curve.

The kurtoic behavior of a distribution defines the amount of "peakedness" the distribution exhibits. A curve with a very high peak yields a positive value that varies with the peak's size, but in all cases indicates that it is more peaked than a normal curve. This severe peaking is referred to as leptokurtosis. The opposite case, or that in which the distribution is flat-topped, is called platykurtosis.

The second type of data processing requirement evolved from the primary evaluation questions which were operational or procedural in nature. Those questions were normally resolved using the manually reduced data in the form of tables, plots, observer logs, etc.

Table C.4 provides a summary of the type of data processing used for each primary test topic. As shown in the table, the first type of data processing, i.e., statistical analysis, was performed for three tests. These were the Northeast Corridor, the Deep Probe Overwater and the NAFEC System Accuracy analyses. The second, more qualitative, data processing was used for the Coastline Signal Anomaly tests, the offshore/oil rig tests, the ship/helo rendezvous and the SAR operations.

Table C.4 indicates the data inputs used for processing as well as the expected data ouputs for each test topic. Careful review of Table C.4 is necessary to facilitate understanding of the data presentation and analysis discussion presented in Section 5.0.

Table C.4 USCG Loran-C Flight Test Program Data Processing Requirements by Test Topic

TEST TOPIC	INPUT				OUTPUT
	ARTS	EAIR	A/B	LOGS	
Northeast Corridor and Spur Routes	X	X	X	X	• Statistical Analysis: TSCT, FTE, ASE, ATE • Measure; Mean $\pm 2\sigma$ • Accuracy Correlation (ARTS vs EAIR)

Deep Probe Overwater		X	X	X	• Statistical Analysis: TSCT, FTE, ASE, ATE
					  • Whenever both EAIR and Loran are available
					  • Measured: Mean $\pm 2\sigma$
					• Manual Plots of Loran-C (lat/lon) vs Desired Track vs EAIR Track Throughout Flight

Coastline Signal Anomaly		X	X	X	• Statistical Analysis: Lat/Lon Indicated Position on Shoreside and Oceanside • Manual Plots of Loran-C vs Desired Track vs EAIR Track • Observer Logs
AC 90-45A/NAS		X	X	X	• Statistical Analysis: TSCT, FTE, ASE, ATE Measured: Mean $\pm 2\sigma$ • Calculated For AC 90-45A Compliance
Offshore/Oil Rigs			X	X	• Statistical Analysis: 2 d_{rms} position error • Raw Airborne Position Data Recorded Manually and on cassette • Manual Plots of Desired vs Achieved Waypoint and Track Information
SAR Operations		X	X	X	• Statistical Analysis: TSCT, FTE, ASE • Actual Aircraft track from EAIR Plots • Track commentary and notes from airborne logs
Ship/Helo Rendezvous			X	X	• Raw Loran-C Position Data Plots • Track commentary and notes from airborne logs

C.1.2.2 Data Processing for AC 90-45A Compliance

The acceptable means of compliance for demonstrating Loran-C capabilities as an area navigation system suitable for NAS operations are currently delineated in FAA Advisory Circular 90-45A, Appendix A, Section 2 [4]. This advisory circular section is further subdivided into accuracy requirements (2.a), system design requirements (2.b), equipment installation specifications (2.c), and flight manual information requirements (2.d). The data collected during the Loran-C flight testing was primarily applicable to the accuracy requirements for compliance. Therefore, in order to understand the need for specific data recording capabilities, the accuracy requirements of Section 2.a of AC 90-45A are briefly reviewed in the following text. The accuracy criteria set forth in this section of the advisory circular are subdivided into separate requirements for three classes of area navigation system. These classes are:

"2.a (1) 2-D RNAV System using Reference Facility for continuous navigation information."

"2.a (2) 2-D RNAV systems which use VOR/DME information from other than the Reference Facilities."

"2.a (3) 2-D RNAV system not using VOR/DME for continuous navigation information."

Obviously, the Loran-C navigation system belongs in category 2.a (3). The accuracy requirements of this subsection are reproduced in the following paragraphs.

2/21/75 AC 90-45A Appendix A Paragraph 2.a

(3) 2-D RNAV System not using VOR/DME for continuous navigation information. The total of the error contributions of the airborne equipment (including update, aircraft position and computational errors), when combined with appropriate flight technical errors listed in 2.a(4) below, should not exceed the following with 95% confidence (2-sigma) over a period of time equal to the update cycle:

	Cross Track	*Along Track*
Enroute	*2.5 nm*	*1.5 nm*
Terminal	*1.5 nm*	*1.1 nm*
Approach	*0.6 nm*	*0.3 nm*

(4) 2-D Flight Technical Errors (FTE) when combined RSS with the errors discussed in (1) and/or (a) above determine the Total System error. The Total System error is used by airspace planners and includes the following specific FTE values for determining cross track position accuracies. Values larger than these must be offset by corresponding reduction in other system errors (see Appendix C). No FTE is used in determining the along track accuracy.

Enroute	*±2.0 nm*
Terminal	*±1.0 nm*
Approach	*±0.5 nm*

Several data acquisition requirements evolve upon thorough examination of these AC 90-45A accuracy requirements. First, total system error in both the cross track and along track dimensions must be quantified. Second, the error contributions of the "airborne equipment" must be measured. (Airborne equipment error includes errors in Loran-C position due to transmission and propagation-induced signal errors). Finally, the value of Flight Technical Error (FTE) must be measured. Upon satisfactorily instrumenting and recording these parameters the procedures of AC 90-45A Appendix C can be used to combine the error elements into an acceptable error budget. These procedures are based on the assumption that the variable errors from each of the error sources are normally distributed and independent. In this case, the errors may be combined in RSS (root-sum-square) fashion in order to demonstrate compliance. That is, the standard deviations, σ_{FTE} and $\sigma_{\text{Airborne Equipment}}$ may be combined by taking the square root of the sum of the squares:

$$\sigma_{\substack{\text{Total}\\\text{System}}} = \sqrt{\sigma^2_{FTE} + \sigma^2_{\substack{\text{Airborne}\\\text{Equipment}}}}$$

Using this recommended equation and rearranging terms, the implied budget for airborne equipment may be calculated from the values for total system error and FTE listed in Appendix A of AC 90-45A. That is,

$$\sigma_{\substack{\text{Airborne}\\\text{Equipment}}} = \sqrt{\sigma^2_{\substack{\text{Total}\\\text{System}}} - \sigma^2_{FTE}}$$

The resulting values for the demonstration of compliance of the Loran-C navigator system have been calculated. These are:

AIRBORNE EQUIPMENT ERRORS

	Cross Track	Along Track
Enroute	1.5 nm	1.5
Terminal	1.1 nm	1.1
Approach	0.3 nm	0.3

The reason that the cross track and along track airborne equipment accuracy requirements are identical is that the FTE error budget values have been removed from the TSCT to derive cross track airborne equipment requirements and by definition (*p. 4-93, par. (4)*), "No FTE is used in determining the along track accuracy requirements". As previously noted, the airborne equipment error budget inherently includes errors in Loran-C position due to transmission and propagation errors. In addition, the airborne equipment error budget includes all signal filtering, processing, computational, output and display errors associated with the airborne Loran-C navigator system.

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APPENDIX D

DETAILED LORAN-C DATA

FROM

THE NORTHEAST CORRIDOR

AND

NAFEC TESTING

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APPENDIX D

This appendix presents the detailed data of the AN/ARN-133 Loran-C navigator gathered in the Northeast Corridor and at NAFEC, Atlantic City, New Jersey. The NAFEC summary data is presented first and followed by the NEC summary data in the following manner:

NAFEC ACCURACY DATA	Page D-4	through	D-13
NAFEC FINAL APPROACH DATA	Page D-14	through	D-17
NEC SUMMARY DATA	Page D-18	through	D-25

In order to provide the reader with an understanding of the relationship between the variables (N error, E error, Loran AT, Loran CT, Total CT and FTE) and the method of calculation, Figure D.1 was constructed. The basic definitions of the variables (TSCT, FTE, ASE and ATE) are covered in Appendix C, Section C.1.2.1. Shown in Figure D.1 is an example taken from page D-13, specifically, the HH52, 11/8/78, approach data for India waypoint. This figure defines the Loran-C indicated course, actual course and the desired course for a course heading of 28° true to runway 04 for the following set of data:

N Error	=	+0.01 nm		
E Error	=	+0.36 nm		
Loran AT	=	-0.18 nm	=	ATC
Loran CT	=	-0.31 nm	=	ASE
Total CT	=	-0.24 nm	=	TSCT
FTE	=	+0.06 nm		

To determine these error components it is necessary to have the latitude and longitude for the Loran-C indicated position (determined from the airborne Loran-C navigator lat/lon data) and the actual position of the aircraft (determined by ground truth radar). The course heading of 28° true defines the Loran-C indicated and actual courses. It is also necessary to understand the following sign conventions and equations which have been historically used for navigation system evaluation.

- Errors right of course are positive and errors left of course are negative.

- Errors ahead of a position alongtrack are positive and errors behind a position alongtrack are negative.

- Errors to the North and East are positive.
- Errors to the South and West are negative.
- Error = Indicated position minus actual position (E = I-A).
- TSCT = FTE + ASE.

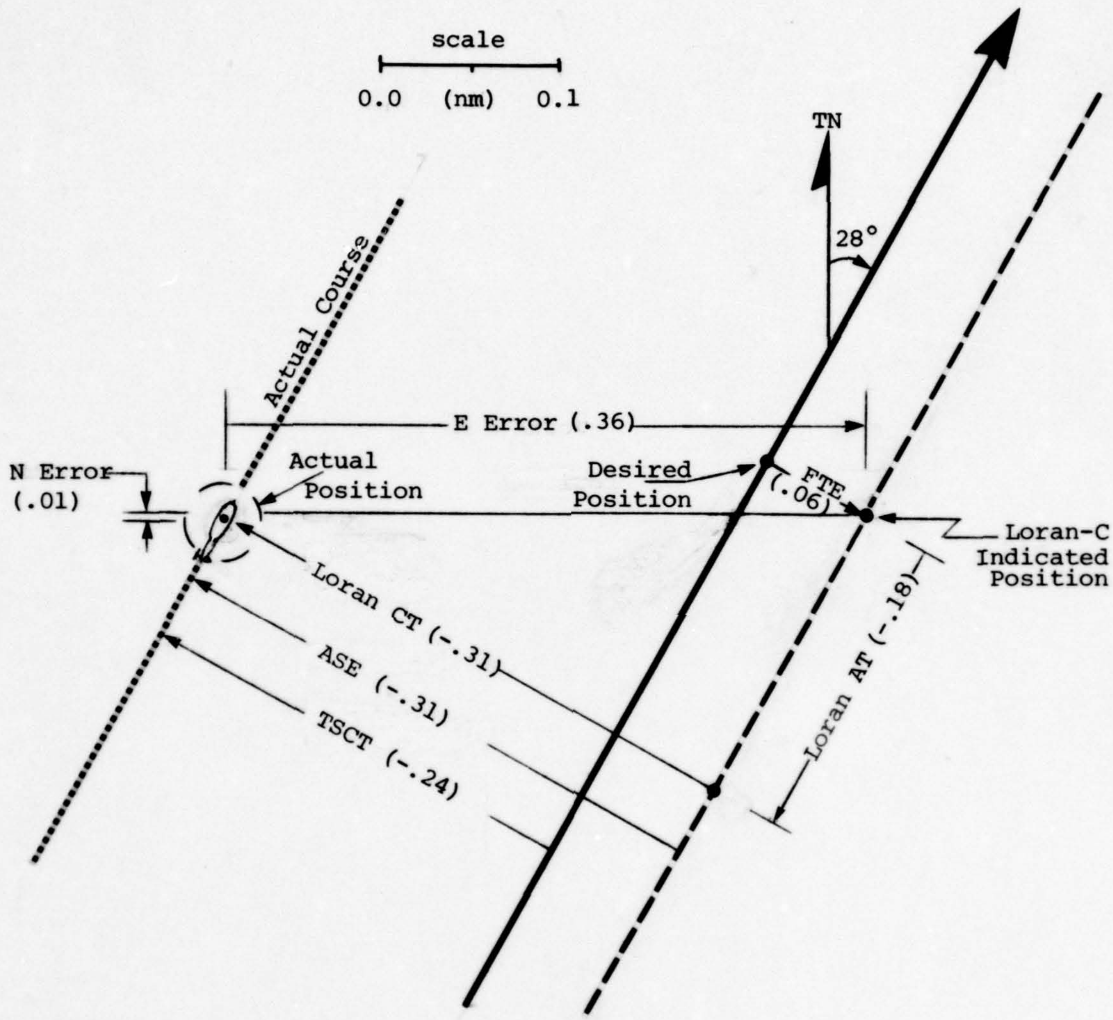
The Loran-C indicated track is also defined as a function of FTE where FTE is the electronically measured amount of crosstrack deviation from the desired course. Since FTE is positive (.06 nm), then the Loran-C indicated course lies .06 nm to the right of the desired course, thus defining the desired course.

Loran AT or ATE is defined as the actual aircraft deviation from the desired position along the flight path. Since the Loran AT error is -.18 nm, the error position is behind the desired position along the flight path.

The Loran CT or ASE is defined as the composite errors contributed by all navigation equipment peculiar to the system being evaluated. This is measured as total deviation perpendicular to the indicated course at the Loran AT position. The Loran CT is -.31 nm, so the error is to the left of the Loran-C indicated course perpendicular to the Loran AT error position by a magnitude of .31 nm.

The TSCT or Total CT is defined as the actual deviation perpendicular to the desired course. The TSCT error being negative (-.24) places the error to the left of the desired course by .24 nm. The procedures described above satisfy the equation TSCT = FTE + ASE.

The N error and E errors are defined as the actual deviation of the Loran-C indicated position from the actual aircraft position along the North and East axes. Therefore, a N error of .01 nm and an E error of .36 nm will define the Loran-C indicated position to the East and slightly to the North of the actual aircraft position.



/NOTE/

1. Error = Indicated minus Actual
2. TSCT = FTE + ASE
   -.24 = .06 - .31
3. ASE = Loran CT
4. Loran AT = Total Alongtrack Error

Figure D.1 System Error Analysis Diagram for NAFEC 11/8178 HOTEL to INDIA Approach Segment

NAFEC Summary Data

HH52 Non-Updated L/λ

7-6-78

Enroute

CAPE MAY

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0773	.0222	.2381	2.6457	196
E ERROR	.3750	.0217	-.1998	1.9110	196
LORAN AT	.0363	.0179	-.1551	2.7292	192
LORAN CT	.4039	.0260	-.0536	1.8300	192
TOTAL CT	.4224	.0410	.1015	3.8483	192
FT ERROR	.0185	.0344	1.0710	5.7601	192

NAFEC Summary Data

HH52 Non-Updated L/λ

7-6-78

Terminal

ROMEO

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0346	.0163	-.0736	2.8349	44
E ERROR	.3536	.0260	2.5734	9.3540	44
LORAN AT	.3359	.0184	1.0955	4.6929	41
LORAN CT	-.1110	.0135	-.1475	3.4906	41
TOTAL CT	-.0901	.0352	.8682	4.3196	41
FT ERROR	.0210	.0424	1.1525	5.0148	41

ROMEO

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0353	.0154	-.3197	2.2352	41
E ERROR	.3561	.0303	2.3443	8.0355	41
LORAN AT	.3419	.0297	1.6062	5.9290	41
LORAN CT	-.1108	.0209	-1.0369	4.6292	41
TOTAL CT	-.0493	.0721	1.2131	3.8209	41
FT ERROR	.0615	.0811	1.6086	5.2041	41

NAFEC Summary Data

HH52 Non-Updated L/λ

7-6-78

Terminal

(continued)

SIERRA

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0948	.0261	.5638	3.2842	140
E ERROR	.3657	.0165	-.3412	4.0842	140
LORAN AT	.0894	.0578	9.0829	98.3096	138
LORAN CT	.3833	.0314	2.5300	21.3892	138
TOTAL CT	.4028	.0509	1.0638	4.9132	138
FT ERROR	.0195	.0535	2.2140	10.2217	138

VICTOR

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0745	.0182	.3679	4.0879	103
E ERROR	.2770	.0201	-.2503	2.6036	103
LORAN AT	.2873	.0224	-.2685	2.6318	104
LORAN CT	.0638	.0186	-.2452	3.3430	104
TOTAL CT	.0911	.0261	-.1900	2.7511	104
FT ERROR	.0229	.0248	.1679	2.2289	104

GULF

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0681	.0242	.7641	4.6235	117
E ERROR	.3397	.0321	-1.2747	5.8417	117
LORAN AT	-.2529	.0273	2.1855	11.0474	112
LORAN CT	-.2379	.0308	.6282	3.0252	112
TOTAL CT	-.2090	.0603	-.4189	3.8336	112
FT ERROR	.0288	.0633	-1.1043	6.7146	112

HOTEL

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0877	.0258	.0832	2.8902	84
E ERROR	.4220	.0285	-.0580	2.4256	84
LORAN AT	-.4189	.0191	.3247	1.9753	79
LORAN CT	.0670	.0331	.3287	2.2874	79
TOTAL CT	.1051	.0534	.3705	2.4297	79
FT ERROR	.0381	.0410	-.7116	3.3137	79

NAFEC Summary Data

HH52 Non-Updated L/λ

7-6-78

Approach

INDIA

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0297	.0173	.0604	2.1525	37
E ERROR	.4322	.0108	.1616	2.4879	37
LORAN AT	-.1751	.0143	.7663	3.0492	35
LORAN CT	-.3915	.0146	-.1222	2.2913	35
TOTAL CT	-.3560	.0480	-.5353	2.2729	35
FT ERROR	.0354	.0476	-.3301	2.2849	35

MAP R/W 04

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0348	.0141	.4086	3.7804	27
E ERROR	.4346	.0142	.0342	2.3008	27
LORAN AT	-.1712	.0116	-.5971	3.5371	27
LORAN CT	-.3976	.0150	.6189	2.7892	27
TOTAL CT	-.3542	.0655	.8977	3.6221	27
FT ERROR	.0433	.0728	.6355	3.3054	27

NAFEC Summary Data

HH52 Updated L/λ

7-10-78

Enroute

VICTOR

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0723	.0338	-.4892	2.9550	189
E ERROR	-.1175	.0311	.2667	3.4048	189
LORAN AT	-.0266	.0316	.2573	3.0348	183
LORAN CT	.1563	.0283	-.2784	2.1131	183
TOTAL CT	.1770	.0370	-.1475	2.7437	183
FT ERROR	.0207	.0386	.2637	4.4618	183

CAPE MAY

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.1101	.0309	-.2850	2.7460	282
E ERROR	-.0527	.0349	.2157	2.5286	282
LORAN AT	-.1108	.0282	1.7870	18.1609	279
LORAN CT	-.0032	.0471	-.5122	6.7217	279
TOTAL CT	.0244	.0725	1.5749	8.1352	279
FT ERROR	.0276	.0684	4.0886	25.2399	279

NAFEC Summary Data

HH52 Updated L/λ

7-10-78

Terminal

ROMEO

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0669	.0230	.1221	3.5776	52
E ERROR	-.0718	.0334	1.9980	7.3411	52
LORAN AT	-.0429	.0186	.0967	4.5445	43
LORAN CT	.0952	.0163	.4920	3.1880	43
TOTAL CT	.0924	.0456	.6285	3.7032	43
FT ERROR	-.0028	.0461	-.2969	2.7311	43

NAFEC Summary Data

HH52 Updated L/λ

7-10-78

Terminal

(continued)

ROMEO

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0590	.0134	.4317	2.5090	52
E ERROR	-.0829	.0208	1.4348	6.1938	52
LORAN AT	-.0448	.0230	1.2947	4.3118	51
LORAN CT	.0895	.0160	-.9590	4.2540	51
TOTAL CT	.1111	.0639	-.0925	1.6908	51
FT ERROR	.0216	.0655	-.1157	1.8484	51

SIERRA

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.1453	.0399	.8260	3.1579	148
E ERROR	-.0277	.0364	-.8107	3.3906	148
LORAN AT	-.1382	.0251	.0995	2.1528	143
LORAN CT	.0552	.0439	-.7427	2.6220	143
TOTAL CT	.0698	.0633	.0417	2.2659	143
FT ERROR	.0146	.0635	-.5562	3.2130	143

VICTOR

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.1502	.0231	.4234	4.3316	143
E ERROR	-.1087	.0315	-.1947	2.2276	143
LORAN AT	-.0895	.0317	-.3996	2.2967	142
LORAN CT	.1725	.0242	-.0880	2.6514	142
TOTAL CT	.1770	.0404	.1348	2.1641	142
FT ERROR	.0046	.0389	.0419	2.4492	142

NAFEC Summary Data

HH52 Updated L/λ

Terminal

(continued)

GULF

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.1165	.0261	.7583	4.3140	94
E ERROR	-.1117	.0294	-1.2326	5.4699	94
LORAN AT	.1561	.0192	.1502	3.8632	87
LORAN CT	-.0578	.0235	-.0246	3.3529	87
TOTAL CT	-.0343	.0483	.2295	3.1956	87
FT ERROR	.0234	.0508	-.0578	2.3806	87

GULF

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.1300	.0271	.0634	4.9914	99
E ERROR	-.0988	.0320	-1.2220	5.0232	99
LORAN AT	.1496	.0190	.3655	4.3534	84
LORAN CT	-.0753	.0237	.1590	2.7636	84
TOTAL CT	-.0635	.0570	-.0225	2.5139	84
FT ERROR	.0118	.0556	-.4081	2.1990	84

HOTEL

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.1011	.0302	.0578	2.3067	86
E ERROR	-.0466	.0277	-.4869	2.6063	86
LORAN AT	.0128	.0208	.3692	2.1871	78
LORAN CT	-.1179	.0375	.2377	2.1105	78
TOTAL CT	-.0970	.0515	-.0086	2.4536	78
FT ERROR	.0209	.0488	1.1109	4.7514	78

HOTEL

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.1195	.0273	.0176	2.2093	81
E ERROR	-.0267	.0296	-.1318	1.9903	81
LORAN AT	-.0167	.0236	.2989	2.1753	74
LORAN CT	-.1230	.0305	.4633	2.1274	74
TOTAL CT	-.1007	.0397	.3829	1.8130	74
FT ERROR	.0223	.0392	1.2269	4.1425	74

NAFEC Summary Data

HH52 Updated L/λ

Approach

INDIA

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0626	.0223	.4902	2.9851	39
E ERROR	-.0184	.0219	.8411	4.2066	39
LORAN AT	.0702	.0155	-.4553	2.8583	26
LORAN CT	-.0051	.0189	.0873	2.0234	26
TOTAL CT	.0018	.0363	.3107	2.7013	26
FT ERROR	.0069	.0470	.0417	2.3169	26

INDIA

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0866	.0261	.3285	2.0650	39
E ERROR	.0061	.0277	1.0052	4.5889	39
LORAN AT	.0748	.0151	-.3939	3.0485	31
LORAN CT	-.0313	.0272	-.0081	1.5728	31
TOTAL CT	.0048	.0528	-.2074	2.1729	31
FT ERROR	.0361	.0622	-.4971	2.2457	31

MAP R/W 04

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0738	.0170	.3261	2.4784	36
E ERROR	-.0215	.0127	-.4259	3.1711	36
LORAN AT	.0745	.0139	-.1884	2.1414	26
LORAN CT	-.0135	.0142	-.1422	2.2217	26
TOTAL CT	-.0062	.0349	.5095	2.1590	26
FT ERROR	.0073	.0276	.4591	2.6266	26

MAP R/W 04

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0796	.0237	-.0315	2.6176	34
E ERROR	-.0070	.0258	.2492	2.8398	34
LORAN AT	.0763	.0163	-.6973	3.0167	32
LORAN CT	-.0334	.0312	-.1904	2.5886	32
TOTAL CT	-.0275	.0796	1.0991	3.7165	32
FT ERROR	.0059	.0914	1.4428	4.4087	32

NAFEC Summary Data

HH3 Non-Updated L/λ

11-8-78

Enroute

VICTOR

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0125	.0486	-.0489	5.6769	86
E ERROR	.2968	.0617	-.2599	2.3256	86
LORAN AT	.2154	.0760	.1707	4.5002	86
LORAN CT	-.1865	.0299	.5309	2.3608	86
TOTAL CT	-.1853	.0514	.0049	2.8173	86
FT ERROR	.0012	.0345	-.3126	3.8047	86

CAPE MAY

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0614	.0341	.4107	4.4985	203
E ERROR	.3553	.0384	-.0656	2.8855	203
LORAN AT	.0434	.0247	-.1359	3.8846	196
LORAN CT	.3800	.0440	.0821	3.7458	196
TOTAL CT	.3886	.0580	.4883	3.0156	196
FT ERROR	.0086	.0437	.0737	2.5470	196

NAFEC Summary Data

HH3 Non-Updated L/λ

11-8-78

Terminal

ROMEO

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	.0084	.0120	.0847	2.1924	43
E ERROR	.3095	.0264	1.5862	6.3607	43
LORAN AT	.2811	.0280	1.0923	5.1663	43
LORAN CT	-.1363	.0179	-1.5080	7.3323	43
TOTAL CT	-.1574	.0255	.2839	2.2490	43
FT ERROR	-.0212	.0390	.7959	4.3232	43

NAFEC Summary Data

HH3 Non-Updated L/λ

11-8-78

Terminal

(continued)

SIERRA

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0434	.0368	.2258	3.6844	133
E ERROR	.3188	.0267	-.0201	3.2206	133
LORAN AT	.1093	.0270	.5258	3.7965	131
LORAN CT	.3156	.0394	-.3151	3.9005	131
TOTAL CT	.3212	.0642	.1162	2.2252	131
FT ERROR	.0056	.0573	.2969	2.6434	131

VICTOR

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0604	.0445	.8762	6.2319	91
E ERROR	.2539	.0545	.0745	2.9078	91
LORAN AT	.2627	.0548	-.2354	2.6183	90
LORAN CT	.0518	.0400	-.4744	3.4152	90
TOTAL CT	.0770	.0499	-1.0155	5.0221	90
FT ERROR	.0252	.0392	-.4044	3.7617	90

GULF

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0197	.0433	.7534	4.1135	16
E ERROR	.2836	.0165	-.2184	2.0275	16
LORAN AT	-.2175	.0538	2.3600	7.7075	12
LORAN CT	-.1724	.0288	-.0240	2.4708	12
TOTAL CT	-.1032	.0187	.1657	1.7641	12
FT ERROR	.0692	.0227	.5424	1.9301	12

GULF

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0339	.0325	-.3126	2.8176	15
E ERROR	.2777	.0428	-1.2230	3.5035	15
LORAN AT	-.2026	.0850	2.3191	7.5402	14
LORAN CT	-.1649	.0301	-.2119	2.8138	14
TOTAL CT	-.0821	.0561	-1.6459	4.3368	14
FT ERROR	.0829	.0673	-1.8500	5.2558	14

NAFEC Summary Data

HH3 Non-Updated L/λ

11-8-78

(continued) Terminal

HOTEL

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0441	.0190	.3276	5.9856	81
E ERROR	.3626	.0521	-.2715	1.9280	81
LORAN AT	-.3489	.0497	.3497	1.9094	77
LORAN CT	.0739	.0263	-.9156	5.3544	77
TOTAL CT	.1142	.0590	1.9636	6.3310	77
FT ERROR	.0403	.0717	2.1892	6.7846	77

HOTEL

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	-.0469	.0192	.1244	3.1078	74
E ERROR	.3571	.0558	-.0113	1.8393	74
LORAN AT	-.3453	.0558	.0546	2.0668	71
LORAN CT	.0782	.0311	.5589	5.0755	71
TOTAL CT	.1248	.0496	-.9341	2.9046	71
FT ERROR	.0466	.0685	-1.4297	3.9535	71

NAFEC Summary Data

HH3 Non-Updated L/λ

11-8-78

Approach

INDIA

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	.0123	.0154	-.3842	3.2021	35
E ERROR	.3613	.0178	.2417	2.3576	35
LORAN AT	-.1752	.0184	-.1144	2.1764	33
LORAN CT	-.3087	.0154	.5428	3.9698	33
TOTAL CT	-.2436	.0307	-.4440	1.8151	33
FT ERROR	.0652	.0327	-.4795	2.0231	33

MAP R/W 04

VARIABLE	MEAN	STD DEV	SKEWNESS	KURTOSIS	# POINTS
N ERROR	.0161	.0075	.0008	3.1087	28
E ERROR	.3599	.0108	-.5008	2.9388	28
LORAN AT	-.1826	.0105	.5451	2.3737	27
LORAN CT	-.3115	.0118	.1014	2.4441	27
TOTAL CT	-.2878	.0420	.4865	1.8673	27
FT ERROR	.0237	.0494	.3044	1.6509	27

NAFEC FINAL APPROACH DATA SUMMARY
NON-UPDATE
HH3
11/3/78

	TSCT		FTE		ASE		# POINTS
	Bias nm	±2σ nm	Bias nm	±2σ nm	Bias nm	± 2σ nm	
RWY 04							
BLTP - FAF	.1786	.0534	.0311	.0668	.1475	.0218	18
BLTP - FAF	.1722	.0604	.0350	.0842	.1372	.5380	16
BLTP - FAF	.1754	.0390	.0279	.0840	.1475	.0442	14
Aggregate	.1755	.0514	.0315	.0766	.1441	.3053	48
FAF - NAP	- .3123	.0630	-.0016	.0634	- .3107	.0184	19
FAF - MAP	- .3001	.0862	.0150	.1080	- .3151	.0314	20
FAF - MAP	- .3221	.0570	-.0117	.0740	- .3104	.0270	23
Aggregate	- .3120	.0707	.0000	.0854	- .3120	.0262	62
RWY 22							
BLTP - FAF	- .1731	.0472	-.0073	.0848	- .1658	.0418	11
BLTP - FAF	- .1741	.0174	-.0044	.0600	- .1697	.0482	9
BLTP - FAF	- .1595	.0748	.0110	.1288	- .1705	.0624	10
Aggregate	-0.1689	0.0526	-0.0003	0.0943	-0.1685	0.0497	30
FAF - MAP	.2876	.0786	.0011	.1098	.2864	.0524	27
FAF - MAP	.2975	.0620	.0104	.0674	.2871	.0508	24
FAF - MAP	.3024	.0620	.0136	.0716	.2888	.0540	22
Aggregate	0.2953	0.0688	0.0079	0.0861	0.2874	0.0517	73
RWY 08							
BLTP - FAF	No EAIR tracking data available						
BLTP - FAF	- .1273	——	.0600	——	- .1873	——	1
BLTP - FAF	- .0909	.0052	.1067	.0116	- .1976	.0128	3
Aggregate	-0.1000	.0366	0.0950	.0477	-0.1950	.0147	4
FAF - MAP	- .1235	.0632	.0189	.0566	- .1423	.0208	18
FAF - MAP	- .0352	.1614	.1061	.1718	- .1413	.0264	23
FAF - MAP	- .0828	.0198	.0550	.0220	- .1378	.0186	24
Aggregate	-0.0772	0.1231	0.0631	0.1270	-0.1403	0.0222	65

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246

NAFEC FINAL APPROACH DATA SUMMARY
NON-UPDATE
HH3
11/6/78

	TSCT		FTE		ASE		# Points
	Bias nm	±2σ nm	Bias nm	±2σ nm	Bias nm	±2σ nm	
RWY 26							
BLTP-FAF	-.1286	.1296	.1821	.1678	- .3107	.0480	14
BLTP-FAF	-.2945	.1620	.0282	.2508	- .3226	.0934	11
BLTP-FAF	-.2704	.0234	.0520	.0328	- .3224	.0142	5
Aggregate	-0.2131	0.2068	0.1040	0.2384	-0.3170	0.0649	30
FAF - MAP	.1501	.0780	.0094	.0636	.1407	.0424	33
FAF - MAP	.1649	.0340	.0123	.0616	.1526	.0450	31
FAF - MAP	.1734	.0578	.0222	.0754	.1512	.0450	32
Aggregate	0.1626	0.0623	0.0146	0.0674	0.1480	0.0450	96
RWY 13							
BLTP-FAF	.2799	.0786	.0053	.0766	.2746	.0498	15
BLTP-FAF	.2786	.0370	.0123	.0888	.2662	.0722	13
BLTP-FAF	.2794	.0530	.0131	.1214	.2663	.0804	13
Aggregate	0.2793	0.0585	0.0100	0.0943	0.2693	0.0666	41
FAF - MAP	.1462	.0324	-.0017	.0682	.1480	.0412	25
FAF - MAP	.1488	.0270	.0082	.0530	.1406	.0438	17
FAF - MAP	.1541	.0424	.0064	.0798	.1477	.0426	22
Aggregate	0.1496	0.0351	0.0037	0.0685	0.1459	0.0422	64
RWY 31							
BLTP-FAF	-.2681	.1182	.0977	.1444	- .3658	.0738	13
BLTP-FAF	-.3076	.0644	.0592	.1376	- .3668	.0790	12
BLTP-FAF	-.2862	.0306	.0764	.0944	- .3625	.0658	11
Aggregate	-0.2868	0.0865	0.0784	0.1293	-0.3651	0.0713	36
FAF - MAP	-.0932	.0316	.0492	.0592	- .1424	.0446	24
FAF - MAP	-.1170	.0388	.0268	.0596	- .1438	.0472	22
FAF - MAP	-.1056	.0262	.0341	.0408	- .1397	.0338	29
Aggregate	-0.1050	0.0367	0.0368	0.0553	-0.1418	0.0412	75

NAFEC FINAL APPROACH DATA SUMMARY
Non-Update
12/18/78
HH52

	TSCT		FTE		ASE		# Points
	Bias nm	±2σ nm	Bias nm	±2σ nm	Bias nm	±2σ nm	
RWY 04							
BLTP-FAF	.3398	.1186	.1915	.1536	.1483	.0514	13
"	.2177	.0628	.0783	.1102	.1398	.0688	12
"	.1839	.0652	.0385	.1248	.1454	.0662	13
AGGREGATE	.2479	.1610	.1034	.1843	.1445	.0612	38
FAF-MAP	-.1738	.2636	.1534	.2896	-.3273	.0348	32
"	-.2956	.1724	.0290	.2076	-.3246	.0462	31
"	-.3127	.1562	.0183	.1368	-.3310	.1096	29
AGGREGATE	-.2586	.2381	.0689	.2530	-.3277	.0826	62
RWY 22							
BLTP-FAF	-.1419	.1008	.0279	.1394	-.1698	.0458	14
"	-.1104	.1256	.0621	.1714	-.1725	.0580	19
"	-.0934	.0630	.0745	.0772	-.1679	.0406	11
AGGREGATE	-.1042	.1069	.0543	.1449	-.1705	.0494	44
FAF-MAP	.3186	.0574	.0146	.0574	.3040	.0218	41
"	.3251	.0480	.0205	.0578	.0347	.0268	43
"	.3185	.0932	.0149	.1070	.3036	.2720	41
AGGREGATE	.3208	.0684	.0167	.0769	.2112	.3003	125
RWY 08							
BLTP-FAF	No airborne data available for BLTP-FAF segments						
"							
"							
AGGREGATE							
FAF-MAP	Only one approach made to Rwy 08						
"							
"	-.1551	.0318	-.0120	.0432	-.1431	.0234	25
AGGREGATE	-.1551	.0318	-.0120	.0432	-.1431	.0234	25

NAFEC FINAL APPROACH DATA SUMMARY
NON-UPDATE
12/18/78
HH52

	TSCT		FTE		ASE		# Points
	Bias nm	±2σ nm	Bias nm	±2σ nm	Bias nm	±2σ nm	
RWY 26							
BLTP-FAF	-.1758	.3306	.1585	.3880	-.3342	.0702	13
"	-.1953	.2654	.1333	.3000	-.3286	.0480	12
"	-.2912	.1072	.0350	.1580	-.3262	.0548	12
AGGREGATE	-.2196	.2681	.1103	.3113	-.3298	.0575	37
FAF-MAP	.2029	.1296	.0461	.1434	.1568	.0320	38
"	.1412	.1418	-.0168	.1514	.1580	.0276	47
"	.1533	.0420	-.0051	.0618	.1584	.0280	45
AGGREGATE	.1634	.1236	.0056	.1349	.1578	.0289	130
RWY 13							
BLTP-FAF	.3658	.0646	.0879	.0866	.2779	.0518	19
"	.2872	.0444	.0088	.0846	.2784	.0526	17
"	.3795	.0992	.1106	.1144	.2689	.0562	17
AGGREGATE	.3450	.1079	.0698	.1279	.2752	.0532	53
FAF-MAP	.1556	.0784	.0004	.1030	.1552	.0420	24
"	.1666	.0590	.0074	.0782	.1592	.0254	23
"	.1429	.0304	-.0161	.0330	.1590	.0152	18
AGGREGATE	.1560	.0633	-.0017	.0810	.1577	.0305	65
RWY 31							
BLTP-FAF	-.0055	.3306	.3750	.3482	-.3805	.0238	10
"	Warn light caused loss of airborne data						
"	Only two segments flown						
AGGREGATE	-.0055	.3306	.3750	.3482	-.3805	.0238	10
FAF-MAP	-.0765	.0872	.0641	.0768	-.1406	.0350	27
"	-.0157	.1320	.1279	.1198	-.1437	.0732	39
"	Only two approaches flown						
AGGREGATE	-.0406	.1298	.1018	.1214	-.1424	.0603	66

Summary Data For Northeast Corridor

9960 Chain

NON-UPDATED

AIRCRAFT	DIR	TSCT		FTE		ASE		ATE		ATD	#	SEGS	FACILITIES
		M	±2σ	M	±2σ	M	±2σ	M	±2σ				
HH52	S	.2563	.7837	-.0068	.1404	.2632	.7876	.1551	.3188	124	616	5	2
HH3	S	.1234	.3397	.0246	.1761	.0988	.3762	-.3703	.7348	188	610	12	3
HH52	N	-.1494	.4087	-.0015	.2343	.0295	.4772	-.1339	.2173	74	393	5	1
HH3	N	-.0814	.3759	.0307	.1462	-.1067	.3570	-.3837	.2667	159	628	10	2
Aggregate	S	.1902	.6192	0.0088	.1622	.1814	.6394	-.1063	.7718	312	1226	17	Not Additive
Aggregate	N	-.1076	.3943	0.0183	.1877	-.0543	.4283	-.2875	.3479	233	1021	15	—
Total Aggregate		0.0549	.6064	0.0131	.1745	.0743	.6012	-.1886	.6422	545	2247	32	—
Non-Updated		0.05	0.61	0.01	0.17	0.07	.60	-.19	.64	545	2247	32	—
UPDATED DATA													
HH52	S	.0508	.5854	-.0116	.1419	.0623	.5591	-.0470	.4284	136	707	10	3
HH52	N	-.0646	.6717	-.0346	.4099	-.0301	.4584	.1717	.3881	46	164	3	1
HH52	N	-.0527	.4352	.0275	.1612	.0252	.3481	.5360	.2169	63	234	4	2
Aggregate	S	.0508	.5854	-.0116	.1419	.0623	.5591	-.0470	.4284	136	707	10	—
Aggregate	N	-.0576	.5446	.0019	.2966	.0024	.4005	.3859	.4673	109	398	7	—
Total Aggregate		.0118	.5802	-.0067	.2114	.0407	.5108	.1089	.6073	245	1105	17	—
Updated		0.01	0.58	0.01	0.21	0.04	0.51	.11	.61	245	1105	17	—
Everything		.0415	.5994	.0111	.1867	.0639	.5752	-.0905	.6901	790	3352	49	—
		.04	.60	.01	.19	.06	.58	-.09	.69	790	3352	49	

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Northeast Corridor Southbound

HH52 Updated 9960 Chain

WAYPOINT NAME	TSCT M	TSCT ±2σ	FTE M	FTE ±2σ	ASE M	ASE ±2σ	ATE M	ATE ±2σ	SEGMENT LENGTH	SECONDARIES	ART FACILITY	POINTS
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11 Hayer	.5629	.1682	-.0058	.0618	.5687	.1770	.3353	.1068	6.48	Nan & Car Bch	EWR	36
12 Gribl	-.2779	.1942	-.0062	.1124	-.2717	.1776	-.2176	.1102	9.55	Nan & Car Bch	PHL	55
13 Bekel	-.1767	.2230	.0040	.1030	-.1807	.1668	-.2026	.1614	19.89	Nan & Car Bch	PHL	124
14 Sinon	-.0922	.2258	-.0249	.2154	-.0673	.0798	-.1707	.0980	13.95	Nan & Car Bch	PHL	86
15 Waggs	.0575	.2508	-.0280	.1378	.0855	.2068	-.1983	.1228	24.97	Nan & Car Bch	PHL	150
16 Wings	.2160	.2392	.0328	.0984	.1832	.1766	-.2032	.1244	4.59	Nan & Car Bch	PHL	25
17 Enger	.4274	.4712	-.0641	.1878	.4915	.3042	.0939	.4780	9.05	Nan & Car Bch	BAL	37
18 Taylo	.5457	.1688	.0278	.0638	.5179	.1514	.3168	.0708	8.06	Nan & Car Bch	BAL	46
19 Rinty	.0583	.5248	-.0050	.1162	.0632	.4988	.1555	.0652	33.40	Nan & Car Bch	BAL	143
20 Clory	-.5074	.0374	-.1600	.0316	-.3474	.0494	.1958	.0584	5.67	Nan & Car Bch	BAL	5
21												
22												
Aggregation	.0508	.5854	-.0116	.1419	.0623	.5591	-.0470	.4284	135.61			707

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Northeast Corridor Southbound

HH52 Non-Updated 9960 Chain

WAYPOINT NAME	TSCT M	TSCT ±2σ	FTE M	FTE ±2σ	ASE M	ASE ±2σ	ATE M	ATE ±2σ	SEGMENT LENGTH	SECONDARIES	ART FACILITY	POINTS
1 Rogee	.6090	.7188	-.0288	.1282	.6378	.6794	.1802	.1738	40.14	Car Bch & Nan	BOS	248
2 Mouro	.1878	.2132	.0049	.1786	.1830	.1158	-.1249	.0902	28.45	Car Bch & Nan	BOS	119
3												
4												
5 Flopp	-.1543	.2110	.0027	.1628	-.1570	.1110	.2078	.0800	11.10	Nan & Car Bch	JFK	108
6												
7 Roler	-.0542	.1598	.0164	.0778	-.0706	.1084	.2961	.0710	5.15	Nan & Car Bch	JFK	39
8 Banka	.0322	.2228	.0139	.0624	.0183	.1936	.3109	.1020	39.49	Nan & Car Bch	JFK	102
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
21												
22												
Aggregation	.2563	.7837	-.0068	.1404	.2632	.7876	.1551	.3188	124.33			616

Northeast Corridor Southbound

HH3 Non-Updated 9960 Chain

WAYPOINT NAME	TSCT M	TSCT ±2σ	FTE M	FTE ±2σ	ASE M	ASE ±2σ	ATE M	ATE ±2σ	SEGMENT LENGTH	SECONDARIES	ART FACILITY	POINTS
1												
2												
3 Clint	.1035	.2120	.0076	.0772	.0959	.1938	-.9919	.1192	47.53	Nan & Car Bch	BDL	126
4 Musik	-.0040	.1634	.4182	.5612	-.4223	.5554	-.4098	.6910	15.38	Nan & Car Bch	BDL	17
5												
6												
7												
8												
9												
10												
11 Hayer	-.2711	.1110	-.0580	.0296	-.2131	.1112	-.3920	.0454	6.48	Nan & Car Bch	PHL	10
12 Gribl	-.1517	.1846	.0248	.0422	-.1764	.1784	-.3860	.0932	9.55	Nan & Car Bch	PHL	40
13 Bekel	-.0501	.1238	-.0043	.0448	-.0458	.1260	-.3349	.1126	19.89	Nan & Car Bch	PHL	77
14 Sinon	.0225	.0586	.0078	.0330	.0147	.0738	-.3224	.0670	13.95	Nan & Car Bch	PHL	59
15 Waggs	.2809	.1580	.0342	.1002	.2467	.1758	-.3397	.0834	24.97	Nan & Car Bch	PHL	90
16 Wings	.3476	.1246	.0029	.0466	.3447	.1212	-.3272	.0413	4.59	Nan & Car Bch	PHL	14
17												
18												
19 Rinty	.2229	.1650	.0157	.0460	.2072	.1666	.0686	.1252	33.40	Nan & Car Bch	DCA	127
20 Clery	.2694	.0718	.0080	.0376	.2614	.0872	.0651	.0936	5.67	Nan & Car Bch	DCA	20
21 Olnee*	.3134	.1114	.0558	.0678	.2577	.1246	-.1653	.0528	3.31	Nan & Car Bch	DCA	19
22 Mawp*	.3465	.2296	.0064	.0508	.3401	.2068	-.1353	.0956	2.81	Nan & Car Bch	DCA	11
Aggregation	.1234	.3397	.0246	.1761	.0988	.3762	-.3703	.7348	187.53			610

*Point-In-Space Approach Segments

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Northeast Corridor Northbound

HH52 Updated 9660 Chain

WAYPOINT NAME	TSCT M	TSCT $\pm 2\sigma$	FTE M	FTE $\pm 2\sigma$	ASE M	ASE $\pm 2\sigma$	ATE M	ATE $\pm 2\sigma$	SEGMENT LENGTH	SECONDARIES	ART FACILITY	POINTS
1												
2												
3												
4												
5												
6												
7												
8 Arcum	-.3355	.7526	-.1568	.7328	-.1787	.1220	.2007	.3076	8.97	Nan & Car Bch	PHL	41
9 Tully	-.1028	.6208	-.0166	.1014	-.0862	.6082	.1142	.5656	24.13	Nan & Car Bch	PHL	61
10 Johns	.1520	.2472	.0285	.1708	.1234	.1420	.2092	.0680	13.02	Nan & Car Bch	PHL	62
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
21												
22												
Aggregation	-.0646	.6717	-.0346	.4099	-.0301	.4584	.1717	.3881	46.12			164

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Northeast Corridor Northbound

HH3 Non-Updated 9660 Chain

WAYPOINT NAME	TSCT M	TSCT ±2σ	FTE M	FTE ±2σ	ASE M	ASE ±2σ	ATE M	ATE ±2σ	SEGMENT LENGTH	SECONDARIES	ART FACILITY	POINTS
1												
2												
3												
4												
5 Zoids	-.4568	.2024	.0241	.1072	-.4809	.2228	-.3701	.3938	16.27	Nan & Car Bch	PHL	69
6 Hamor	-.3280	.1552	.0329	.1024	-.3609	.1082	-.4232	.1208	10.58	Nan & Car Bch	PHL	49
7 Paoli	-.1620	.1806	.0256	.1640	-.1876	.1246	-.6338	.0762	13.98	Nan & Car Bch	PHL	66
8 Arcum	-.0205	.3612	.0402	.4086	.0217	.0644	-.3848	.0704	8.97	Nan & Car Bch	PHL	41
9 Tully	-.0101	.0778	.0361	.0618	-.0463	.0364	-.3809	.0722	24.13	Nan & Car Bch	PHL	101
10 Johns	-.0021	.0450	.0377	.0460	-.0398	.0238	-.4063	.0712	13.02	Nan & Car Bch	PHL	26
11 Banka	.0271	.1058	.0141	.1002	.0131	.0672	-.4230	.1014	26.23	Nan & Car Bch	PHL	88
12												
13												
14												
15												
16												
17												
18 Meeow	.0545	.1866	.0371	.1102	.0174	.1354	-.2285	.1060	32.07	Nan & Car Bch	BOS	123
19 Slott *	.0149	.1108	.0351	.1158	-.0202	.0774	-.3479	.0696	8.50	Nan & Car Bch	BOS	37
20 Mawp *	-.0208	.0724	.0329	.0954	-.0536	.0424	-.3523	.0532	5.51	Nan & Car Bch	BOS	28
21												
22												
Aggregation	-.0814	.3759	.0307	.1462	-.1067	.3570	-.3837	.2667	159.26			628

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Northeast Corridor Northbound

HH52 Non-Updated 9660 Chain

	WAYPOINT NAME	TSCT M	TSCT ±2σ	FTE M	FTE ±2σ	ASE M	ASE ±2σ	ATE M	ATE ±2σ	SEGMENT LENGTH	SECONDARIES	ART FACILITY	POINTS
1													
2													
3													
4													
5	Zoids	-.5079	.1302	.0100	.0950	-.5179	.1368	.0631	.0748	16.27	Nan & Car Bch	PHL	11
6	Hamor	-.3935	.1578	.0265	.1380	.4200	.0852	.0447	.0914	10.58	Nan & Car Bch	PHL	83
7	Paoli	-.1781	.3148	.0221	.2812	-.2002	.1094	-.1944	.0792	13.98	Nan & Car Bch	PHL	96
8	Arcum	-.0888	.3518	-.0557	.3382	-.0331	.0536	-.1946	.0512	8.97	Nan & Car Bch	PHL	60
9	Tully	.0137	.1822	-.0117	.1752	.0253	.1232	-.1867	.0764	24.13	Nan & Car Bch	PHL	143
10													
11													
12													
13													
14													
15													
16													
17													
18													
19													
20													
21													

Northeast Corridor Northbound

HH52 Updated 9660 Chain

WAYPOINT NAME	TSCT M	TSCT ±2σ	FTE M	FTE ±2σ	ASE M	ASE ±2σ	ATE M	ATE ±2σ	SEGMENT LENGTH	SECONDARIES	ART FACILITY	POINTS
1												
2												
3												
4												
5												
6												
7												
8 Arcum	-.1071	.1742	.0266	.1974	-.1337	.1144	.4668	.2836	8.97	Nan & Car Bch	PHL	35
9 Tully	-.0561	.1452	.0134	.1182	-.0695	.1196	.4953	.0986	24.13	Nan & Car Bch	PHL	97
10 Johns	.0295	.1688	-.0117	.0780	.0412	.1470	.5179	.0764	13.02	Nan & Car Bch	PHL	58
11												
12												
13												
14												
15												
16 Droun	.4501	.2796	.1109	.1794	.3392	-.1324	.7046	.1154	17.24	Nan & Car Bch	BDL	44
17												
18												
19												
20												
21												
22												
Aggregation	.0527	.4352	.0275	.1612	.0252	.3481	.5360	.2169	63.36			234

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APPENDIX E

OPERATIONAL PROBLEMS SUMMARY

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APPENDIX E

This appendix offers a detailed summary of the operational problems and events encountered during selective tests of the AN/ARN-133 Loran-C navigator flight test. These events are further discussed and categorized for qualitative analysis in Section 5.1.5. This appendix is organized chronologically and divided into five operational problem areas. The first three (ATC, Pilot/Copilot and Loran-C Navigator) are NAS environment operation problems while the last two (Airborne Data and Tracking Data) are primarily data recovery related problems.

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OPERATIONAL PROBLEMS SUMMARY

DATE	AIRCRAFT	ROUTE	OPERATIONAL PROBLEMS					DISPOSITION
			AIR TRAFFIC CONTROL	PILOT/COPILOT	LORAN-C NAVIGATOR	AIRBORNE DATA	TRACKING DATA	
-1-78	HH3	DEEP PROBE OVERWATER OFF NAFEC		The pilot made a visual approach to RWY 08 due to 1.0 nm CTE in Navigator from cycle jump.	WARN light on at approximately 38 nm DTW NEW ERA and out at approximately 14 nm DTW NEW ERA. WARN light out approx. 100 nm DTW CHARLIE and continually regaining and losing lock. WARN light on at 101 nm DTW HOTEL and out at 91 nm DTW HOTEL. WARN light on at 60 nm DTW HOTEL and out at 43 nm DTW HOTEL. WARN caused a cycle jump producing an approx. 1.0 nm CTE.	No Airborne Data. Improper operation of recorder.	EAIR followed for 100 nm out and picked up aircraft about 100 nm on the way back (the expected range of EAIR tracking). EAIR followed for approx. 110 nm out and back.	Reflown on 6-2-78 for Airborne Data. Reflown on 11-7-78 to meet test requirements for airborne data 200 nm out and back.
-2-78	HH3	DEEP PROBE OVERWATER OFF NAFEC		Pilot turned aircraft south approx. 41 nm DTW CHARLIE to intercept DELTA-HOTEL leg due to turbine surges.	Loran-C Navigator began experiencing weak SNR's (i.e., 70220) approx. 74 nm and 64 nm DTW CHARLIE. WARN light on a 48 nm DTW CHARLIE for approx. 2 min. Weak SNR's encountered 128 nm DTW HOTEL.			
-13-78	HH52	SAR TEST OFF CAPE MAY		Copilot incorrectly added 10° Mag. Var. to the programming for true bearing of the Search Patterns. This caused the Creeping Line and Sector Search Patterns to be shifted by 10° E. On pattern 1 of Sector Search, segment 3-4, pilot missed waypoint because of WARN light occurrence. at 0.26 nm to WPT. Pilot made turn on to segment 4-1, but Navigator had not sequenced because of WARN. Copilot noticed DTW increasing so after about a minute, Pilot and Copilot decided to go back and try to intercept leg where the Navigator had not advanced. By executing a manual leg change, the aircraft intercepted pattern 1, segment 4-1. Upon reaching next waypoint (pattern 2, segment 1-2), the pilot had a CTE of Right 0.14 nm and the Navigator did not sequence to next segment. However, the pilot turned on the approx. bearing for next segment. The aircraft traveled approx. 1.30 nm, having developed a CTE of 1.25 nm, before the copilot recognized the problem and executed a manual leg change, the aircraft recovered to desired track in approx. 1 min. At RENDEZVOUS Waypoint, Copilot was supposed to program at 3.0 nm R. offset. However, he preprogrammed a 0.3 nm R. offset. Pilot followed needle to offset course and realized the error. Copilot corrected mistake immediately. From programming the 0.3 nm offset to programming the 3.0 nm offset was approximately 30 sec.	WARN light flashed on Creeping Line pattern 1, segment 2-3. Did not disturb navigation. WARN light on at 0.26 nm to end of segment 3-4, pattern 1 of Sector Search, lasting approx. 9 seconds. Pilot made turn on segment 4-1 but Navigator had not sequenced because of WARN.			

OPERATIONAL PROBLEMS SUMMARY

DATE	AIRCRAFT	ROUTE	OPERATIONAL PROBLEMS					DISPOSITION
			AIR TRAFFIC CONTROL	PILOT/COPILOT	LORAN-C NAVIGATOR	AIRBORNE DATA	TRACKING DATA	
7-6-78	HH52	NAFEC NAS TEST	Pilot cut first approach to MAP RWY 04 approx. 1.0 nm short because of traffic and per ATC's request to land on RWY 31. On first departure, ATC requested an early turn onto enroute segment ROMEO-SIERRA due to traffic on approach. As a result, ROMEO waypoint was missed so Navigator did not auto advance to next leg. The aircraft accumulated a 0.43 nm CTE prior to the manual leg change to ROMEO-SIERRA. Recovery time, from early turn through stabliz-ation on next leg was about 54 sec.	When the Copilot executed a manual leg change for ROMEO to SIERRA, waypoints 8 to 1 were used which causes the Navigator in the auto mode to decrement waypoints auto-matically. Therefore upon arriving to SIERRA (WPT 1), the Navigator decremented 1 to 9 (Cape May). Within 40 seconds the pilot and copilot noticed a navigation problem, so the copilot programmed "CLR, Leg Chng, Insert". This procedure caused the navigator to decrement from 9 to 8 (Cape May to ROMEO). Immediately seeing that this was also wrong, the copilot programmed "CLR, Leg Chng, 1, 2, Insert", sequencing the Navigator from SIERRA to GOLF. Recovery from initial waypoint decrement to course stablization required about 90 sec, accumulating an approximate 0.5 nm CTE. Pilot cut second approach to RWY 04 short by approx. 1.3 nm because of traffic in pattern and decided to fly around east side of airport at higher altitude. Copilot left Navigator in manual waypoint sequence mode after second approach. Neither pilot or copilot noticed the Navigator DTW display increasing until they had overshot ROMEO waypoint by about 1.3 nm, at which time the copilot executed a manual leg change for the ROMEO-CAPE MAY leg.		Lat/Lon data only avail-able for first portion of test (Cape May, VICTOR, GULF, HOTEL, INDIA, MAP 04), due to improper report programming of Navigator.		
7-10-78	HH52	NAFEC NAS TEST		Pilot overshot turn on 1st GOLF to HOTEL leg by approx. 0.3 nm. The Loran-C Navigator sequenced WPT's properly. Pilot overshot turn on 1st approach of Hotel to INDIA leg by about 0.5 nm after the Navigator had sequenced legs. Pilot overshot turn on SIERRA-VICTOR to VICTOR-GOLF leg by about 0.6 nm at VICTOR WPT due to large obtuse angle between legs. Pilot overshot turn on last approach of HOTEL to INDIA leg by about 0.5 nm after Navigator had sequenced legs. Anticipating turn on to ROMEO-SIERRA leg, the pilot began turn about 0.7 nm prior to ROMEO. Immediately recognizing the error, the pilot turned the A/C back towards the desired track. Upon zeroing the CDI needle, the leg sequenced. The pilot accumulated a 0.5 nm CTE while executing a late turn.				

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OPERATIONAL PROBLEMS SUMMARY

DATE	AIRCRAFT	ROUTE	OPERATIONAL PROBLEMS: AIR TRAFFIC CONTROL	PILOT/COPILOT	LORAN-C NAVIGATOR	AIRBORNE DATA	TRACKING DATA	DISPOSITION
7-11-78	HH52	SAR TEST OFF CAPE MAY		Pilot displayed much difficulty in meeting the waypoint arrival circle of 600 ft. diameter due to some WPT's fluctuating as much as 0.25 nm. In the interest of fuel the flight crew opted to negate two sectors and the depart/return search from the Sector Search portion of the test.	Of the 25 waypoints used during this test, 7 waypoints were missed due to strong signal interference. Many other waypoints displayed large CTE and DTW fluctuation within approx. 0.25 nm. Investigation produced two possible interference sources: a) Radio transmissions from Annapolis b) The Space Environment Laboratory, ERL, in Boulder, Co., recorded a solar flare level in excess of X15 on 7-11-78 at 1700Z. The SAR test occurred between 1500 Z and 1703 Z. The Return Search function of the Navigator failed to operate properly during the Creeping Line portion of the test, and instead provided guidance to a different leg.			
10-19-78	HH52	SHIP/HELO RENDEZVOUS TEST		On the first approach using Technique 2, two attempts were made before an approach was completed. For the second approach using Technique 2, the pilot and copilot switched duties. To complete this approach required 5 attempts due to the very high workload necessary to perform Technique 2 approach, combined with the lesser skill of the copilot on the Loran-C Navigator.	Loran-C Navigator could not lock-on 9960 chain, so test was performed on 7980. Eleven minutes into the test on the first approach, a WARN light occurred indicating not in track and float. The Navigator was also recommending a secondary change from Grangeville, Jupiter to Grangeville, Carolina Beach.			
11-1-78	HH3	NEC, Southbound from Otis AFB to Andrews AFB	One region not aware of flight test due to ARTS coordination problem. Resulted in an inordinate amount of radio communications to acquire "time hacks" and handoffs. Communication with ATC at JFK, PHL and DCA were difficult due to large number of aircraft in the control space. It was not uncommon to wait as much as 2 to 3 minutes for a response.	Aircraft was approx. 0.5 nm left of track on segment ROLER to BANKA as observed on the Navigator. Two minutes prior to arriving to TOLAN WPT, the Navigator recommended a secondary change from Caribou, Nantucket to Nantucket, Carolina Beach. Just as the secondary change was completed the Navigator advised "missed waypoint". The pilot immediately reversed course in order to intercept the TOLAN, SLONE segment at TOLAN WPT. Upon arriving to WINGO WPT, the copilot and pilot agreed that the bearing of the leg seemed wrong. Both assumed that the Navigator skipped a waypoint, when in actuality it had not. Rather than go back, the copilot decided to advance to the next leg manually, WINGO to EGNER which was the leg they were presently on.	A "WARN" light indicating "not in track", appeared approx. 4 minutes after completing the PISA into DCA. It lasted for 1 minute, then "WARN" on 1 minute later and lasted for the remainder of the flight (approximately 10 min.).	HH3 crew member was assigned the task of Loran-C data recorder operation. Inadequate explanation of system operation resulted in complete loss of airborne data for the 11-1-78 and 11-2-78 flights.	While under PHL ARTS, the controller notified the test aircraft that BAL ARTS was inoperative. PHL advised that they would follow the aircraft as far as possible. DCA ARTS had not been required for this test.	Test was reflown on 11-5-78 to acquire airborne data.

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OPERATIONAL PROBLEMS SUMMARY

DATE	AIRCRAFT	ROUTE	OPERATIONAL PROBLEMS: AIR TRAFFIC CONTROL	PILOT/COPILOT	LORAN-C NAVIGATOR	AIRBORNE DATA	TRACKING DATA	DISPOSITION
11-2-78	HH3	NEC, Northbound, Andrews AFB to PHL to NAFEC	Radio congestion between aircraft and ATC was high for DCA and PHL. Controllers were not aware of test due to ARTS coordination problem.	Copilot had programmed Andrews AFB as a WPT to navigate to from present position after takeoff. This procedure brought the aircraft back over the field in order to sequence to the next leg automatically, while circling back over the field, a second time, still within departure and arrival altitudes, confusion set in between the crew and ATC. As a result the pilot took over control of the Navigator from the copilot for about 30 sec. to get the desired track bearing of the segment Andrews to BERNY WPT. At several miles to HOTEL WPT, the pilot departed from test to go direct to NAFEC due to engine surging and communications failure at the same time.		Loss of airborne data in same manner as 11-1-78.	DCA ARTS had not been required for this test.	Reflew test on 11-5-78.
11-3-78	HH3	NAFEC Final Approach Test (RWY's 04, 22, and 08)			The BLTP (Base Line Turn Point) WPT for RWY 08 was wrong, therefore providing improper navigation for the segment BLTP to AP. This resulted from a Lat/Lon calculation error prior to the NAFEC Final Approach Test.			
11-5-78	HH3	NEC, Southbound, OTIS AFB to Andrews AFB and Northbound PHL to NAFEC	The flight test observer could not listen to controller communications due to the VHF receiver being inoperative. The pilots, to communicate with ATC, had to listen on the HF receiver and transmit on VHF. This procedure had to be related to every controller so that the pilot could get equivalent VHF and HF frequencies. It was also necessary to explain the purpose of test and support needed to each controller due to ARTS coordination breakdown. While on segment PAOLI to HOTEL, 8.2 nm from PAOLI at 2500 ft. MSL, PHL Approach Control requested that the USCG test aircraft turn to a heading of 040° to avoid a B707 on approach. The controller related that had the USCG aircraft not deviated it would have passed over the B707 with less than 1000 feet altitude separation. Total deviation amounted to about 2.0 nm left of course. Much radio communication was necessary to convince PHL Departure to hold us on radar as long as possible for test purposes.	The crew did not notice the "ADVISE" light for secondary change until 4 minutes later when the "WARN" light came on, because of the awkward, temporary position of the Loran-C Navigator for the flight test. Thirty seconds after the "WARN" light flashed at CLINT WPT, the copilot changed the secondaries from Nantucket Carolina Beach, back to Caribou, Nantucket without checking the advise and warn displays. When the Navigator would not accept Caribou, Nantucket, the copilot checked the advise light, which was now recommending secondaries Nantucket, Carolina Beach. When this change was effected, an ATD difference of 0.68 nm northeast and a CTD difference of 0.80 nm Northwest occurred. To this the pilot/copilot interpreted as being poor signal strength of the secondaries and again attempted a change from Nantucket, Carolina Beach to Caribou, Nantucket. When this failed, the copilot agreed to using Nantucket, Carolina Beach. After arriving on segment CLORY to OLNEE the pilot thought that the Navigator had skipped the RINTY WP, when in reality it had not. The pilot proceeded to turn the aircraft back while the copilot selected a leg change of RINTY to CLORY. This leg change provided an increasing DTW CLORY, which is proper, because the aircraft was still	An "ADVISE" and "WARN" light occurred about 11 min & 15 min respectively after takeoff from Otis AFB. It was indicating "not in track" and "secondary change recommended". The "WARN" and "ADVISE" cleared about 20 seconds after the secondaries were changed from Caribou, Carolina Beach to Caribou, Nantucket. "WARN" light occurred at 39.3 nm to MOURO WPT, prior to intercepting the NEC. The WARN light lasted for about 20 sec. indicating "not in track". The WARN light was out about 1 minute before another "WARN" light occurred indicating "not in track" for about 20 sec. This was remedied by a secondary change from Caribou, Nantucket to Nantucket, Carolina Beach which was advised by the Navigator 4 minutes before the first WARN light came on. When the secondary change was executed, an ATD difference of 0.16 nm to the East occurred and a CTD difference of 0.4 nm South occurred. Upon arriving to CLINT WPT, the "WARN" flashed. Just after passing over FLOPP WPT, the "WARN" and "ADVISE" light came on indicating "not in track" and "float" for about 18 sec. A "WARN" and "ADVISE" light occurred about 1 min after	"Time hacks" were very difficult to get with accuracy because the VHF communication receiver that the flight test observer used was inoperative. The portion of the flight where the pilot departed the PISA on segment CLORY to OLNEE and flew to RINTY again was deleted from the airborne data for the error analysis. Airborne data for Andrews to BERNY to MOISH on northbound portion of test lost due to WARN light. Deviation from course by PHL Approach on segment PAOLI to HOTEL was edited out for error analysis.	Tookoff from Otis AFB with 300 ft ceilings and less than 1 nm visibility. Could not fly the scheduled route to ROGEE WPT due to worsening weather conditions. Pilot flew A/C to coast where ceiling was 600' and broken; but still too low to be picked up by BOS or NAS. The weather permitted the aircraft to climb to 1550 ft. MSL at which time we intercepted the MOURO to CLINT segment where we acquired lock-on with NAS ARTS radar. Subsequently, no BOS tracking data was accomplished and only a small portion of NAS tracking was available. No tracking data was available from JFK ARTS, BAL ARTS (on Southbound portion of test) and BAL ARTS (on the northbound portion of the test). Tracking data from PHL ARTS on segment PAOLI to HOTEL dropped out at HOTEL waypoint.	

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DATE	AIRCRAFT	ROUTE	OPERATIONAL PROBLEMS: AIR TRAFFIC CONTROL	PILOT/COPILOT	LORAN-C NAVIGATOR	AIRBORNE DATA	TRACKING DATA	DISPOSITION
-5-78 (Cont.)	HH3 (Cont.)	NEC, SOUTHBOUND, OTIS AFB TO ANDREWS AFB AND NORTHBOUND PHL TO NAFEC (Continued)		in the turn and was deviating from the CLORY to RINTY segment. The pilot and copilot became confused by this information so the copilot selected a leg change from their present position to WPT RINTY in order to refly the PISA. Pilot intercepted and overshot MOISH to RUSEY leg of northbound flight by 0.42 nm (according to the Navigator) due to losing Loran-C navigation (WARN light).	passing ROLER WPT, lasting about 2 min. and 5 sec. Ten seconds later the Loran-C Navigator display blanked, indicating a possible electrical system shutdown for about 12 seconds. The Navigator required about 36 seconds to regain signal strength to an operating level. A "WARN" light occurred after takeoff from Andrews AFB about 3.8 nm to BERNY WPT. It lasted about 5 minutes and 50 sec., indicating "not in track". During this time period the crew had decided to fly direct to NAFEC. The aircraft had deviated about 10 nm when the WARN light went out. By then the aircraft had passed by BERNY and MOISH waypoints. The copilot sequenced waypoints to intercept MOISH to RUSEY segment.			
-9-78	HH3	NEC, NORTHBOUND, NAFEC TO PHL TO OTIS AFB		When the pilot transitioned to the NEC from leg VICTOR, PAOLI to PAOLI, ARCUM, he overshot PAOLI WPT by approx. 0.6 nm. The pilot recovered to a 0.07 nm left CTE in about 55 seconds. At 37 nm to ROLLER, the pilot deviated right of track by about 1.7 nm to avoid traffic. On leg DROUN to DANEY at 5.8 nm to DANEY, an "ADVISE" light came on. Three minutes later the copilot saw it and cleared it without looking to see what it was recommending. It was probably recommending a secondary change from Nantucket, Carolina Beach to Caribou, Nantucket. As a result the advise light did not come back on and the Navigator operated on secondaries Nantucket and Carolina Beach all the way to Otis AFB.	A "WARN" and "ADVISE" light indicating "not in track" and "float" appeared on leg JONNS to BANKA and lasted about 1 min. and 43 sec. It is interesting to observe from the airborne data that the Navigator lost signal lock for the first 54 seconds, then the power apparently shut down for about 13 seconds. For the remaining 36 seconds, the Navigator spent it reacquiring signal strength.	At 5.8 nm to TULLY WPT, the tape became tangled in the Airborne Data Recording System. This resulted in the loss of about 13.4 nm of airborne data. The portion of the flight where the pilot overshot PAOLI WPT was deleted for the error analysis.	PHL ARTS and JFK ARTS had no tracking data for USCG HH3 test the aircraft.	
-14-78	HH52	NEC, NORTHBOUND, NAFEC TO PHL TO BOS		On transition to the NEC from segment SIERRA, PAOLI to PAOLI, ARCUM, the pilot overshot PAOLI by about 0.78 nm left of track. On leg BANKA to ROLER, the pilot was flying a heading of 056° Mag. North for 12 nm, rather than a heading of 076° Mag. North. He had misunderstood what the copilot said the bearing should be. The pilot thought he was having to compensate for large wind corrections due to his inability to center the CDI and maintain a 056° heading.	A "WARN" light occurred indicating "not in track" on segment DROUN to DANEY, at about 30 nm to DANEY. The copilot changed secondaries from Nantucket, Carolina Beach to Caribou, Nantucket, but signal strength was too low for lock-on. The copilot then changed the Loran-C GRI chain from 9960 to 9930, but signal strength was still to low. No lock-on occurred for the remainder of the flight to BOS.	The portion of leg BANKA to ROLER where the aircraft was on the wrong heading was deleted for the error analysis. No airborne data available for NEC Northbound portion of route, DROUN through PISA at BOS, due to Loran-C Navigator being inoperative.	No tracking data for BOS due to cancellation of test because of Loran-C Navigator inoperation.	The Loran-C Navigation and filters in the HH52 were exchanged with an HH3 based at the USCG Air Station, OTIS AFB, on 11-15-78.

OPERATIONAL PROBLEMS SUMMARY

DATE	AIRCRAFT	ROUTE	OPERATIONAL PROBLEMS					DISPOSITION
			AIR TRAFFIC CONTROL	PILOT/COPILOT	LORAN-C NAVIGATOR	AIRBORNE DATA	TRACKING DATA	
11-15-78	HH52	NEC, SOUTHBOUND, OTIS AFB TO NEC TO BRAINARD FIELD		About one minute after takeoff the "ADVISE" light came on, but the copilot immediately cleared it without investigating the reason for its occurrence.	An "ADVISE" light appeared about one minute after takeoff, but was immediately cleared. It may have been recommending a secondary change from Caribou, Nantucket to Nantucket, Carolina Beach. Although, when SNR's were inspected 7 minutes later, signal strength on Caribou, Nantucket was strongest. After landing at Brainard Field it was observed that a secondary change was recommended to Nantucket, Carolina Beach.		No tracking data was available from Bradley ARTS.	This flight transitioned from the NEC to Brainard Field at about 17 nm to CLINT WPT.
12-5-78	HH52	NEC, NORTHBOUND, NAFEC TO PHL TO BOS	Communications with ATC was difficult throughout test due intermittent malfunctions of the communications receiver on the test aircraft.	On the transition to the NEC from segment SIERRA, PAOLI to PAOLI, ARCUM, the pilot overshot and missed PAOLI WPT by about 0.6 nm due to strong crosswinds. While on segment ARCUM to TULLY, the copilot intended to get distance to MAWP at BOS from present position by inputing "CLEAR", WPT, 0,1 (MAWP), INSERT", but instead executed a leg change by inputing "CLEAR, LEG CHG, 0,1 (MAWP), INSERT". This provided bad steering to the pilot for the desired leg. Recovery took about 18 seconds with no significant CTD encountered. After passing BANKA WPT, the pilot accumuated a 0.9 nm right CTE on the BANKA to ROLER segment due to strong crosswinds. Recovery took more than 3 minutes. During the PISA to Logan Int., the copilot noticed a large distance error to AVONS WPT (3035 nm after about 5 min. The error was not noticed sooner because the heading only changed by 5° east from the previous course. The copilot discovered a lat/lon input error for AVONS and corrected it in about 3 minutes, while navigating to AVONS. Permission was then granted by approach control to abrupt the approach and begin again at MEEOW waypoint.	A "WARN" light flashed about 2.8 nm DTW BANKA. A "WARN" and "ADVISE" light appeared about 32.2 nm to ROLER, lasting about 39 seconds, followed by an apparent power shutdown to the Navigator lasting about 10 seconds. About 45 more seconds were required for the Navigator signals to come back up to operating level. Total down time amounted to 1 min. and 34 sec. After passing over ROLER WPT, the copilot noticed that a leg change did not "automatically" sequence from BANKA, ROLER to ROLER, MAUDE as it was supposed to. After about 1.8 nm from ROLER a manual leg change was executed. The leg change from IGORR to DROUN did not auto sequence. After about 0.5 nm from IGORR a manual leg change was executed. When the copilot changed secondaries at 29 nm to MEEOW, from Nantucket, Carolina Beach to Caribou, Nantucket, the airborne data showed an ATD difference of 0.49 nm to the NE and a CTD difference of 0.03 nm to the NW.	The portion of segment ARCUM to TULLY where the pilot improperly operated the "Interwaypoint Distance, BRNG" function of the Navigator was deleted due to invalid airborne position data relative to the desired track. A portion of segment BANKA to ROLER where the pilot was grossly off course due to winds was deleted for the error analysis. The PISA to Logan Int. where the bad lat/lon was encountered, was deleted for the error analysis.	Communications receiver became inoperative, intermittently, so the test aircraft did not receive handoff from PHL to JFK until problem was discovered abeam JFK Int., but not soon enough to acquire ARTS data recovery.	

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OPERATIONAL PROBLEMS SUMMARY

DATE	AIRCRAFT	ROUTE	OPERATIONAL PROBLEMS: AIR TRAFFIC CONTROL	PILOT/COPILOT	LORAN-C NAVIGATOR	AIRBORNE DATA	TRACKING DATA	DISPOSITION
12-6-78	HH52	NEC, SOUTHBOUND ROGEE THROUGH CLINT WAYPOINTS		By the time the aircraft had arrived at ROGEE WPT, the pilot had accumuated a 0.17 nm right CTE and therefore missed the waypoint. A manual leg change was executed within 10 seconds, but a CTE right of course increased to 0.37 nm on the new leg, ROGEE to MOURO. Recovery was made in approximately 40 seconds. On the MOURO to CLINT segment, about 47.6 nm DTW CLINT the aircraft deviated left of course by 0.74 nm and remained about 0.6 nm off course for approx. 2.6 nm while the pilot and copilot were studying a map. Again at about 40.5 nm to CLINT the aircraft deviated right of course by 0.34 nm for approx. 3 nm while the crew was studying a map. At about 35 nm DTW CLINT, the aircraft deviated left of course by 0.85 nm for about 3.0 nm, while the crew was studying a map.	At approximately 33.0 nm DTW CLINT, the copilot executed a secondary change from Caribou, Nantucket to Nantucket, Carolina Beach. In doing so, an ATD difference of 0.20 nm to the northeast was encountered as well as, a CTD difference of 0.23 nm to the Northwest. At approximately 8.6 nm to MUSIK, a "WARN" and "ADVISE" light occurred indicating "not in track" and "float", lasting about 1 min. and 50 sec. At approximately 4.8 nm DTW MUSIK, a "WARN" and "ADVISE" light occurred indicating "not in track" and "float", lasting about 2 minutes.	No airborne data is available for the last 10 nm of the flight to CLINT WPT.	BDL and NAS ARTS were only able to provide tracking data for the first half of the flight.	Sikorsky Spur route testing was also performed on this date.
12-7-78	HH52	NEC, SOUTHBOUND, MUSIK TO FLOPP	Much radio communication was necessary to get "time hacks" from ATC.					Sikorsky Approaches to NY and NY Airways Spur Routes performed on this date.
12-19-78	HH52	NEC, SOUTHBOUND, NAFEC TO TOLAN WPT TO DCA	PHL ARTS refused to affect a radar handoff to BAL ARTS as requested. PHL would only give him the BAL frequency. The pilot initiated the handoff to BAL. During the PISA to DCA on segment RINTY to CLORY, BAL handed the test aircraft over the DCA Tower. DCA Tower told the pilot that he was not in his airspace, since the tower only covers a 10 nm radius, so he handed him over to DCA Approach. DCA Approach told the pilot that he was still in BAL airspace. Although the PISA was completed with a high degree of workload, the obvious question lays, operationally, in who controlled the airspace.		The Navigator froze in the WPT POSITION display. Reason was not indicated in the airborne data. The Navigator was "reinitialized" to alleviate the problem.		No tracking data for the WAGGS to WINGO segment.	The Allentown Spur test was also performed on this date.

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1-15-79	HH52	NEC, NORTHBOUND		While navigating to ROLER from BANKA WPT, the copilot inadvertantly programmed a waypoint over the BANKA WPT, and therefore lost navigation for the desired route. During the "WARN" portion of the PISA to LOGAN, the copilot or pilot apparently changed the auto waypoint sequence to manual by mistake. This did not affect the PISA, because a manual leg change was necessary after the "WARN" was over.	At approx. 16 nm to JONNS WPT while transitioning to the NEC from NAFEC, a "WARN" and "ADVISE" light occurred indicating "not in track" and "float" lasting about 2 min. and 22 sec. About 30 seconds prior to crossing DANEY WPT on the DROUN to Daney leg, an "ADVISE" light recommended a secondary change from Nantucket, Carolina Beach to Carabou, Nantucket. A CTD shift of about 0.25 nm to the Northwest was observed. While on the PISA to LOGAN for segment MEEOW to SLOTT a "WARN" and "ADVISE" light indicated "not in track" and "float" lasting about 2 minutes and 55 seconds. During the "WARN" the aircraft overshot SLOTT WPT by about 0.5 nm	The airborne data recording system malfunctioned and distorted the information on the tape for the entire flight.	ARTS tracking data available only with NAS for this date. Aircraft was too low (1500 ft. MSL) for BDL.	
1-16-79	HH52	NEC, SOUTHBOUND, BOS TO DCA		The pilot overflew the BANKA to TOLAN leg by about 1.0 nm to the left of track. He did not notice auto leg change to TOLAN. The pilot missed the arrive circle of WPT GRIBL of the GRIBL to BEKEL leg. The pilot overflew the turn onto leg CLORY to OLNEE at CLORY WPT having missed the arrive circle, and overshot leg to right by 1.0 nm. CLORY to OLNEE defines the segment of the PISA to DCA.	The "ADVISE" light appeared on segment MOURO to CLINT, at about 32 nm DTW CLINT. A secondary change was recommended from Caribou, Nantucket to Nantucket, Carolina Beach.	The Loran-C airborne data recorder malfunction intermittently during the flight, rendering about 2/3's of the data unrecoverable.	The only ARTS tracking facilities that were able to provide data were NAS and JFK ARTS.	
1-18-79	HH52	NEC, NORTHBOUND DCA TO PHL		In transitioning to the MOISH to RUSEY leg, the pilot overflew the MOISH WPT by about 0.5 nm to the right of track. The pilot overflew the PAOLI to ARCUM leg at WPT PAOLI by about 0.5 nm to the left of track. It took nearly 3 min before the pilot recovered, primarily due to winds. On leg ARCUM to TULLY, the copilot noticed a discrepancy in the distance/bearing to TULLY. By checking the WPT lat/lon, it was discovered that the lat/lon position was wrong. The copilot changed the TULLY coordinates while navigating to the bad coordinates. Upon hitting "Insert" on the Navigator, correct navigation was provided.			Tracking data available only from PHL ARTS.	

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